REVIEW-LEVEL EARTHQUAKE EVALUATION:

RECOMMENDATIONS FOR IPEEE IMPLEMENTATION AT THE PALO VERDE NUCLEAR GENERATING STATION NEAR WINTERSBURG, ARIZONA

FINAL REPORT
(REVISION 2)

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ABSTRACT

This report presents the basis and methods for evaluating an appropriate earthquake review-level for the Palo Verde Nuclear Generating Station (PVNGS). The resulting recommended review-level earthquake (RLE) is intended for use as a screening and reporting basis in implementing the seismic portion of the Individual Plant Examination of External Events (IPEEE) at the PVNGS site, in response to NRC Generic Letter 88-20, Supplement 4.

The approach in this study has been to compare a number of key seismic hazard measures for the PVNGS site with corresponding results for nuclear power plants in the central and eastern U.S. that have been placed in the 0.3g RLE bin. Implementing a set of relative (plant-to-plant) comparisons and binning procedures similar to those developed in the NUREG-1407 document, and implementing a wider variety of alternate comparisons, the results of the present study do not support a default RLE binning assignment of 0.5g for the PVNGS site; rather, a 0.3g binning assignment is indicated.

In addition to developing the basis for establishing the recommended 0.3g RLE assignment, this study also develops general recommendations on an appropriate scope of effort to undertake in seismic-IPEEE implementation for the three nuclear reactors at the Palo Verde station.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

Section 1

INTRODUCTION

1.1 GENERAL BACKGROUND AND PURPOSE OF STUDY

This report presents the bases and methods for evaluating an appropriate earthquake review-level for the Palo Verde Nuclear Generating Station (PVNGS) located in Arizona (2 miles south of Wintersburg). The resulting recommended review-level earthquake (RLE) is intended for use as a screening and reporting basis in implementing the seismic portion of the Individual Plant Examination of External Events (IPEEE) at the PVNGS site, in response to NRC Generic Letter 88-20, Supplement 4 (1). Specific guidance on use of the RLE in seismic-IPEEE implementation can be found in NUREG-1407 (2) and EPRI NP-7498 (3).

Generic Letter (GL) 88-20, Supplement 4 specifies an RLE value (or review bin) for each nuclear power plant licensed for commercial operation in the United States. In that context, PVNGS is described as a "Western United States site whose default bin is 0.5g unless the licensee can demonstrate that the site hazard is similar to those sites east of the Rocky Mountains that are found in the 0.3g bin." Without the benefit of a consistent set of site-specific seismic hazard results, one would be unable to ascertain a definitive RLE value for the PVNGS site; therefore, in the absence of further analysis, a RLE value of 0.5g would, by default, be considered generally conservative.

Information and results from the Final Safety Analysis Report (4) and a preliminary seismic hazard study (5), however, imply a very low seismic hazard at the PVNGS site. Furthermore, the actual ground-motion spectrum used in the seismic design of the plant substantially exceeds that required as a Safe Shutdown Earthquake (SSE) for plant licensing. These points suggest that a RLE value of 0.5g may not be clearly warranted for IPEEE implementation at the PVNGS site, but rather, a RLE value of 0.3g may be appropriately justified in light of more-detailed investigation and comparison of the seismic hazard.

Consequently, for the purpose of better defining the site-specific hazard and the seismic input appropriate for IPEEE implementation and safety evaluation, Arizona Public Service (APS) has undertaken a seismic hazard study and uncertainty investigation (6) for the Palo Verde station. The primary application of the present study is to make use of these seismic

hazard results (together with hazard results, derived similarly, for plant sites in the central and eastern U.S.) in determining a consistent RLE value (0.3g or 0.5g) that is appropriate for IPEEE implementation at the PVNGS site.

In addition to developing a basis for establishing a recommended RLE for the PVNGS site, a second purpose of this study is to develop general recommendations on an appropriate scope of effort to undertake in seismic-IPEEE implementation of each of the three nuclear reactors at the Palo Verde station.

1.2 BACKGROUND ON OBJECTIVES OF THE IPEEE

The IPEEE program is being conducted in response to NRC's Severe Accident Policy Statement (7). That statement describes the motivation, understanding, and formal policy basis to be considered in resolving issues related to potential severe reactor accidents; key highlights of the Commission's statement are noted as follows:

- Based on currently available information, the Commission concludes that existing nuclear power plants pose no undue risk to public health and safety;
- Based on NRC and industry experience with plant-specific PRAs (Probabilistic Risk Assessments), however, systematic plant examinations are beneficial in identifying plant-specific vulnerabilities to severe accidents for which safety improvements may be justified;
- Each existing plant should, therefore, perform a systematic examination to identify any plant-specific vulnerabilities, and report the results to the Commission.

Hence, a fundamental objective of severe accident policy is to verify the widely held belief that plants pose no "undue risk" and that "all reasonable steps are taken to reduce the chances of occurrence of a severe accident involving substantial damage to the reactor core and to mitigate the consequences of such an accident should one occur." The Individual Plant Examination (IPE) is a key element of the implementation program developed by the NRC Staff for meeting this objective and for developing a plan for integrated closure of severe accident issues (8). The IPEEE is that facet of the overall IPE effort which specifically addresses the potential for severe reactor accidents due to external causes. As outlined in the NRC documents for IPEEE guidance, the specific objectives of the IPEEE are, for each utility in charge of operating an existing plant, to (2):

- "Develop an appreciation of severe accident behavior,"

- "Understand the most likely severe accident sequences that could occur at the licensee's plant (under full power operating conditions),"

- "Gain a qualitative understanding of the overall likelihood of core damage and fission product releases, and"

- "If necessary, to reduce the overall likelihood of core damage and radioactive material releases by modifying, where appropriate, hardware and procedures that would help prevent or mitigate severe accidents."

In its Severe Accident Policy Statement, the NRC clarifies the level of effort the IPEs should involve:

> "licensees of each operating reactor will be expected to perform a limited-scope, accident safety analysis designed to discover instances (i.e., outliers) of particular vulnerability to core melt or to unusually poor containment performance, given core-melt accidents."

Hence, a limited-scope plant investigation, that makes effective use of insights yielded by past detailed investigations, aimed at effectively identifying cost-effective mitigations of plant-specific vulnerabilities, is the course intended by the NRC Commissioners for implementation of IPEs in severe accident policy resolution. The recommendations in this report for plant seismic review level and overall scope of seismic IPEEE implementation are consistent with this "limited-scope" intent of systematic evaluations as described in the NRC Severe Accident Policy Statement.

1.3 ROLE OF THE RLE IN IPEEE IMPLEMENTATION

It is generally recognized that, when directed by a well-qualified Seismic Review Team (SRT), seismic margin assessment (SMA) methodology and walkdown procedures are quite thorough and efficient at identifying "outliers" (or "weak-links"). In fact, many knowledgeable engineers believe that such a well-focused, well-directed, thorough plant walkdown is the single-most important aspect of plant examination for identifying potential severe-accident vulnerabilities. Hence, the SMA approach (with recommended enhancements) has been endorsed by the NRC (2) as a basis for conducting the seismic IPEEE.

In this context of seismic margin assessment (vis-à-vis the context of a PRA analysis), the role of the RLE in IPEEE implementation is most meaningful. In particular, the RLE serves to fix the limits for SMA screening of potential outliers in the seismic IPEEE review and also delineates the ground-motion spectrum to be used in response and capacity analyses (HCLPF calculations). Generally speaking, the RLE simply defines a uniform "reporting limit" for component capacities and potential vulnerabilities. In other words, components with computed HCLPF capacities less than the RLE (i.e., with capacities that would not meet or exceed the level of seismic demand imposed by the RLE spectrum) would need to be reported as potential vulnerabilities and would need to be addressed for further evaluation.

The RLE ground motion specified for IPEEE implementation by the NRC (2) is the 5%-damped, median NUREG/CR-0098 (9) spectral shape [for the appropriate site condition (soil or rock)] anchored to the RLE peak ground acceleration (PGA) value (0.3g or 0.5g). Hence, the RLE ground motion is not a site-specific basis for plant evaluation (i.e., its shape is not based explicitly on expected earthquake characteristics and its amplitude is not determined from considerations of plant-specific hazard or risk); rather, the RLE is a standard or reference ground-motion demand for plant evaluation.

The advantage of a standardized RLE ground motion is to ensure that capacity calculations are performed on a consistent, uniform basis from plant to plant. This advantage facilitates one-to-one comparisons of plant-level capacities and clarifies industry-wide insights on general understanding of plant capacities (without any specific influence of the seismic hazard).

For decisionmaking purposes, however, considerations of site-specific seismic hazard and risk (in addition to plant capacity alone) are required for a consistent and meaningful decision process. For this reason, therefore, the RLE is unsuitable as a decision criteria; hence, the NRC has clarified that the RLE should not serve as an ultimate acceptance level (2).

As a result, whether a plant is reviewed at a level of 0.3g or 0.5g would be immaterial in terms of bottom-line plant safety and in terms of any actual modifications undertaken for safety enhancement, provided the selected RLE is of sufficient amplitude to reveal the set of potential meaningful safety enhancements. Consequently, the RLE should be large enough to screen-in components and systems for which meaningful potential safety enhancements, if any, may be found. On the other hand, if the selected RLE is too large, unnecessary analyses will be performed and unnecessary expenses will be incurred with no added benefit in terms of plant safety. In this case, no additional safety enhancements that are meaningful in terms of cost-effectiveness will be found to justify the additional effort.

Because a review-level of 0.5g would generally imply a substantially greater effort in plant evaluation costs than would a 0.3g review level, there should be a clearly definitive basis for expecting that the additional cost in plant analysis is necessary in discovering a more complete set of meaningful, cost-effective potential safety enhancements.

1.4 RELEVANCE AND ASPECTS OF IPEEE CLOSURE

The aspect of IPEEE implementation that deals with bottom-line decisionmaking is IPEEE closure. NRC severe accident policy specifies that backfit criteria (i.e., cost-benefit comparisons) serve as the ultimate basis for deciding whether or not potential safety enhancements are justified. Industry guidelines, criteria, and a decisionmaking framework have been developed for the purpose of achieving systematic seismic IPEEE closure [see Reference (3)]. The closure criteria employ risk-based screening and decision elements for evaluation of alternative safety enhancements based on cost-benefit analyses. The present study does not specifically address such decision-based criteria; however, it is important to emphasize the critical significance of these criteria in establishing the link between IPEEE implementation and the objectives of severe accident policy. For perspective, the RLE (as a screening and reporting level) does not serve as a criterion for satisfying severe accident policy objectives of delineating cost-effective enhancements. For an optimal, efficient IPEEE implementation, the RLE would be selected so that only the truly viable safety enhancements, as respects IPEEE closure, are screened in for evaluation in the IPEEE closure process. Determining whether or not an effective (and efficient) IPEEE implementation can be accomplished at a review level of 0.3g for the Palo Verde station is a primary consideration in this study.

1.5 REPORT ORGANIZATION AND OVERVIEW

In the following section, additional background on IPEEE implementation and on the use of the RLE is presented to introduce the notation, concepts and basis for the RLE evaluation approach. The primary inputs required for RLE evaluation are site-specific seismic hazard results; Section 3 summarizes the results of the seismic hazard analysis for the PVNGS site. A brief description of the hazard results used for characterizing the seismic threat at central and eastern U.S. plants is also provided to establish the basis for subsequent hazard comparisons. Section 4 outlines the approach for the RLE evaluation, and describes the procedures and methods for the seismic hazard comparisons.

It is important to note that, among a variety of comparisons demonstrated in this study, a general RLE evaluation procedure that includes use of the hazard measures, frequency-dependent weighting criteria, and overall binning philosophy, as described in Appendix A of NUREG-1407, has been employed on a consistent basis in this study for the RLE evaluation

at PVNGS. All comparisons of seismic hazard measures, however, are here based on EPRI seismic hazard results, as the hazard analysis for the PVNGS site was conducted in a manner similar and consistent with the EPRI hazard methodology. Results and comparisons of computed hazard measures (both as a function of vibration frequency and as composite [or scalar] values) are provided in Appendices A, B, C and D (whereas Section 5 summarizes and tabulates the results of plant-to-plant comparisons used in developing the RLE recommendations). All hazard comparisons are relative (plant-to-plant), and the relative binning results should be similar to those obtained if LLNL hazard methods were implemented. As opposed to performing a formal binning analysis (for instance, using the clustering methodology described in Appendix A of NUREG-1407), simple comparisons of various seismic hazard-based measures are made with central and eastern U.S. plants falling in the 0.3g full-scope and focused-scope bins (i.e., the hazard bounds for plants in these bins were assumed to denote general references for assessing whether or not the PVNGS site would belong in these bins).

Considering this basis, Section 5 presents the comparisons of seismic hazard measures for the PVNGS site with those for the 0.3g full-scope and focused-scope sites in the central and eastern United States (CEUS). Section 5 also presents comparisons of hazard measures for PVNGS against the two CEUS plants assigned to the 0.5g RLE bin in NUREG-1407. Section 6 then presents the conclusions and recommendations from the study analyses.

The hazard comparisons developed in this study are based on three primary types of results: (1) probabilities of exceeding the NUREG/CR-0098 (median, 5%-damped) spectrum, (2) probabilities of exceeding the (plant-specific) seismic design-basis spectrum, and (3) uniform hazard spectra (UHS). Uniform hazard spectra are considered for annual exceedance frequencies of 10^{-3}, 10^{-4}, and 10^{-5}; probabilities of exceeding the NUREG/CR-0098 spectrum are considered for cases where the spectrum is anchored to 0.3g and to 0.5g. In every case, comparisons are made separately for mean, median, and 85th-fractile hazard statistics.

Hazard results in each case are plotted versus vibration frequency (i.e., as spectra) for 51 total plant sites. These plots enable general qualitative comparisons to be made among plants; more definitive, quantitative comparisons, however, are difficult to derive from these plots because of variations in relative (plant-to-plant) hazard across vibration frequency. To facilitate the development of more meaningful, quantitative comparisons, a variety of scalar hazard measures are computed from the spectral results, and these scalar measures are compared for all plants. For comparisons of UHS results, the scalar measures include the peak spectral acceleration over the frequency range of 2 to 10 Hz and the average value

of spectral acceleration over the same frequency range. For comparisons of exceedance probabilities (for either the NUREG/CR–0098 spectra or the design-basis spectrum), the scalar measures include: the peak exceedance probability over the range of 2 to 10 Hz; the average value of exceedance probability over the same frequency range; a composite measure of exceedance probability (where the result for 2.5 Hz, 5.0 Hz, and 10.0 Hz is each given two-sevenths [2/7] weight and the result for PGA is given the remaining one-seventh [1/7] weight); and an alternate composite measure of exceedance probability (where the result for 2.5 Hz, 5.0 Hz, and 10.0 Hz is each given one-third [1/3] weight and the result for PGA is given zero weight). The basis and significance for use of each of these scalar measures is discussed in Section 4.

In comparing the scalar hazard measures from plant to plant, results are sorted (ordered) from highest to lowest, and ranked; the plant with the highest hazard measure is assigned a ranking of one (1), whereas the plant with the lowest hazard measure is assigned a ranking of fifty-one (51). Because all 50 plants (other than PVNGS) belong to the 0.3g RLE bin, any ranking greater than one for PVNGS would support placing PVNGS into the 0.3g bin based on the particular hazard comparison.

Plant rankings for PVNGS are also established among results for the two CEUS plants in the 0.5g RLE bin [i.e., those CEUS plants (Pilgrim and Seabrook) where the licensees have committed to perform a seismic PRA]. In these comparisons, a ranking of three for PVNGS would support not placing PVNGS into a 0.5g bin, but would support an RLE assignment of 0.3g.

To provide, prior to further discussion, a synopsis of comparison results and of the recommendations of this study, the following conclusions are highlighted:

- For the PVNGS site, all scalar measures derived from probabilities of exceeding the 0.3g NUREG/CR–0098 (median, 5%-damped) spectrum lie consistently within the range of corresponding values obtained for central and eastern U.S. plants in the 0.3g focused-scope or full-scope SMA bin. For the composite exceedance probability, the rankings for PVNGS range from 4-of-51 to 5-of-51; for the alternate-composite exceedance probability, all rankings are 2-of-51; for the peak exceedance probability (over 2 to 10 Hz), the rankings for PVNGS vary from 4-of-51 to 5-of-51; and for the average exceedance probability (over 2 to 10 Hz), all rankings are 2-of-51. Therefore, measures of probabilities of exceeding the 0.3g NUREG/CR–0098 spectrum demonstrate the PVNGS site hazard to be similar to that at plant sites east of the Rocky Mountains that are in the 0.3g RLE bin.

- For the PVNGS site, all scalar measures derived from probabilities of exceeding the NUREG/CR-0098 (median, 5%-damped) spectrum anchored to 0.3g PGA lie consistently below the range of corresponding values obtained for the two central and eastern U.S. plants in the 0.5g (PRA) bin. In other words, comparisons of all statistics of each of the four measures of probability of exceeding the 0.3g NUREG/CR-0098 spectrum produce a ranking of 3 for PVNGS among the 0.5g plants. Hence, the seismic hazard at Palo Verde is unlike (i.e., consistently lower than) that for CEUS plants assigned to the 0.5g RLE (PRA) bin.

- For the PVNGS site, all scalar measures derived from probabilities of exceeding the NUREG/CR-0098 (median, 5%-damped) spectrum anchored to 0.5g PGA lie consistently within the range of corresponding values obtained for central and eastern U.S. plants in the 0.3g focused-scope or full-scope SMA bin. Therefore, measures of probabilities of exceeding the 0.5g NUREG/CR-0098 spectrum also demonstrate the PVNGS site hazard to be similar to that at plant sites east of the Rocky Mountains in the 0.3g RLE bin.

- On an absolute basis, the mean and 85th-fractile composite probabilities of exceeding the 0.3g NUREG/CR-0098 (median, 5%-damped) spectrum are both considerably less than the 10^{-4} level, whereas the median composite probability is modestly less than 10^{-5}. Criteria in NUREG-1407, related to these absolute comparisons, demonstrate that an RLE assignment of 0.5g would not be supported at the PVNGS site.

- For the PVNGS site, values of uniform-hazard peak spectral acceleration (across the 2 to 10 Hz frequency range) lie within the upper range of corresponding values obtained for central and eastern U.S. plants in the 0.3g focused-scope or full-scope SMA bin. In addition, values of average spectral acceleration (over 2 to 10 Hz) lie effectively within the upper range of corresponding values obtained for the 0.3g plants. Hence, measures of uniform-hazard spectral acceleration for the PVNGS site are similar to measures of hazard at plant sites east of the Rocky Mountains in the 0.3g RLE bin.

- In addition, demonstration of seismic margin (i.e., a plant HCLPF capacity) at the level of 0.3g implies an extremely low seismically induced core-damage frequency for each PVNGS reactor; a mean value of less than 7.0×10^{-6} core damages per year from earthquakes is suggested for a HCLPF capacity of at least 0.3g.

The above results support the requirement in NUREG-1407 of demonstrating that the hazard at Palo Verde is similar to the hazard at plant sites east of the Rocky Mountains in the

0.3g bin; they further show the hazard at Palo Verde to be lower than the hazard at CEUS plant sites in the 0.5g RLE bin; and they also indicate that demonstrating seismic margin for PVNGS at a level of 0.3g is sufficient in showing that PVNGS poses no "undue risk" to public health and safety.

In addition to these points, and related to procedures implemented in NUREG–1407 to distinguish among 0.3g full-scope and focused-scope plants, the following observations are also noted:

- For the PVNGS site, scalar probabilities of exceeding the seismic design basis are indistinguishable from the lower range of results for the 0.3g focused-scope plants. The comparative rankings (ranging from 32-of-44 to 35-of-44) are even more favorable than those obtained above (for probabilities of exceeding the NUREG/CR–0098 spectrum) because of the greater level of conservatism in the seismic design basis for PVNGS compared to the other plants.

  Implementing the approach described in NUREG–1407 for delineating among full-scope and focused-scope 0.3g plants, PVNGS would apparently qualify as a 0.3g focused-scope site. NUREG–1407 precludes the exclusive use of focused-scope procedures in the IPEEE analysis of PVNGS. It is considered worthwhile, however, that the use of focused-scope procedures (on a non-exclusive basis) be pursued where found to be appropriate. In particular, results of the first IPEEE analysis, based on 0.3g full-scope SMA application for a single reactor unit, would be used as a basis for judging the applicability and adequacy of focused-scope procedures at the remaining two reactor units, and such procedures would be implemented as appropriate at these units.

The detailed basis for these statements and tentative recommendations, together with related results, are the subject of the remaining sections of this report.

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Section 2

BACKGROUND ON IPEEE

This section provides a brief overview of the IPEEE process from a very general perspective. The intent of this overview is to clarify the use of the RLE ground-motion spectrum in plant screening, response analysis, capacity calculations, and IPEEE reporting. Additionally, the discussion introduces fundamental notation used consistently throughout this document.

2.1 GENERAL OVERVIEW OF PROCESS

Figure 2–1 presents a general overview of the IPEEE process. The first three elements of this process are common to guidelines that are found in both reports NUREG–1407 (1) and EPRI NP–7498 (2). The other elements, which pertain to the seismic IPEEE closure process, and the framework for considering alternative actions for plant modification, are explicit steps in the seismic-IPEEE implementation approach recommended by industry in EPRI NP–7498.

As indicated in Figure 2–1, the first step in the overall process is to conduct a plant walk-down and perform a plant screening analysis. The plant screening analysis produces a set of seismic-IPEEE *outliers*. Next, response analyses (e.g., structural dynamics calculations) are performed to determine expected seismic demands for particular plant components (structures or equipment) of interest. The purpose of the response analyses is to enable HCLPF capacities to be assessed for the outlier components. Outliers with computed HCLPF capacities that do not meet the specified RLE ground-motion demand are denoted as *remaining outliers* or *potential vulnerabilities*. In accordance with NUREG–1407, these remaining outliers are reported in the IPEEE submittal and require further evaluation as to their significance.

The evaluation process for remaining outliers (i.e., closure process) identifies whether or not alternative actions, in the form of *potential safety enhancements* that mitigate the potential vulnerabilities, need to be addressed. The closure process also assesses the cost-effectiveness of potential safety enhancements and indicates any resulting *safety enhancements* found to be justified and appropriate for implementation through modification of plant hardware or procedures. Any ultimate actions (or inactions) in response to potential vulnerabilities are clearly explained and justified by documentation in the IPEEE submittal.

As discussed in Section 1, the RLE does not delimit a plant-specific acceptance level, and therefore, serves no direct purpose in closure evaluation. The primary use of the RLE pertains to the plant screening level, the seismic input for capacity evaluations, and the HCLPF reporting basis (i.e., the first three elements in the overall process of Figure 2-1); each of these aspects of the seismic IPEEE is described briefly below.

2.2 PLANT SCREENING

The guidance on the EPRI seismic margins methodology provided in the report EPRI NP-6041 (3) [1991 revision to Reference (4)], or on the NRC seismic margins methodology provided in NUREG/CR-4334 (5), may be used as a basis for screening components. In particular, Table 2-3 (for structures) and Table 2-4 (for equipment) of EPRI NP-6041 provide conservative screening criteria, for various components, associated with alternative review levels defined by a range of spectral-acceleration screening limits. For instance, distinct screening criteria are defined for the following RLE spectral acceleration ranges: S_a less than 0.8g, S_a between 0.8g and 1.2g, and S_a greater than 1.2g. For plants with a RLE value of 0.3g PGA, the screening criteria applicable for $S_a < 0.8g$ are used in IPEEE implementation, whereas screening criteria for S_a values between 0.8g and 1.2g are used for plants with an RLE value of 0.5g PGA (2). Hence, selection of an RLE value determines at what level plant screening will be performed.

Components screened-out based on the applicable screening criteria require no further evaluation, indicating that the specified S_a screening limits are conservatively satisfied. Components screened-in as outliers cannot be said, on a conservative basis, to satisfy the specified S_a screening limits, and calculations are required to ascertain whether or not the outlier-component capacities in fact meet the screening limits (and/or the RLE spectral acceleration limits). Hence, the screening criteria themselves are somewhat conservative with respect to the actual screening-limit values. In other words, even if the screening criteria are not satisfied entirely, the associated screening limits may still be shown as being met through actual calculations.

In addition to the conservatism inherent in seismic-margin screening relative to the applicable screening limits, in seismic IPEEE implementation there is also conservatism in the seismic margin screening limits relative to the RLE ground-motion spectrum. Figure 2-2 indicates this conservatism (over the vibration frequency range of interest) for both the 0.8g S_a screening limits relative to the 0.3g RLE ground-motion spectrum, and the 1.2g S_a screening limits relative to the 0.5g RLE ground-motion spectrum.

As discussed in Section 1, the RLE ground-motion spectrum for IPEEE review is defined by the 5%-damped, median NUREG/CR-0098 (6) spectral shape [for the appropriate site condition (rock or soil)] anchored to the RLE PGA value. The lower RLE spectrum in Figure 2-2 has a RLE PGA value of 0.3g, whereas the upper RLE spectrum has a RLE PGA value of 0.5g. The lower screening spectrum in Figure 2-2 consists of a S_a limit of 0.8g and a spectral velocity (S_v) limit of 20 in/sec, whereas the upper screening spectrum consists of a S_a limit of 1.2g and a S_v limit of 30 in/sec. The basis for these screening limits, and for their use in the EPRI SMA screening tables, is presented in reports EPRI NP-6041 and EPRI NP-7498. The actual screening values of 0.8g and 1.2g compare conservatively with the maximum spectral accelerations of 0.636g and 1.06g, respectively, for the 0.3g-RLE and 0.5g-RLE ground-motion inputs.

The two sources of conservatism in plant screening just noted are both important to keep in mind when evaluating an appropriate ground-motion level for seismic-IPEEE implementation. The implications of these conservatisms are that components for which HCLPF capacities substantially in excess of the RLE demand will ultimately be demonstrated, will be initially screened-in as outliers. For a plant with a 0.3g review level, it is likely that some components with actual HCLPF PGA capacities as high as 0.35 to 0.40g (or so) may be screened-in for analysis.

2.3 RESPONSE ANALYSES AND CAPACITY CALCULATIONS

Another primary purpose of the RLE ground-motion spectrum, in addition to fixing the SMA screening limits and criteria, is to characterize the ground-motion input for component response analyses and HCLPF capacity calculations. In accordance with EPRI NP-6041, the RLE ground-motion demand should be applied at the free field as opposed to the basemat of the structure. Hence, for soil sites, it may be appropriate to conduct a soil-structure interaction analysis to develop the shaking input to specific components. The RLE ground-motion would serve as a reference or control motion for this purpose. The guidance provided in EPRI NP-6041 may be used as one basis for developing in-structure response spectra, when necessary, for either rock or soil conditions. Based on the results of the response analyses, HCLPF capacities may be computed using either the conservative deterministic failure margin approach or the fragility analysis method.

2.4 HCLPF REPORTING

The RLE ground-motion spectrum delimits the level at which HCLPF capacities must be documented. In other words, components either screened-out during the plant walkdown or found to have computed HCLPF capacities in excess of the RLE, do not require further

evaluation. Only components found to have a computed HCLPF capacity lower than the RLE level need be documented as requiring further attention. A complete list of the outliers screened-in during the SMA walkdown should be reported, but no additional evaluation would be indicated for those components (outliers) with computed HCLPF capacities larger than the RLE.

2.5 REFERENCES

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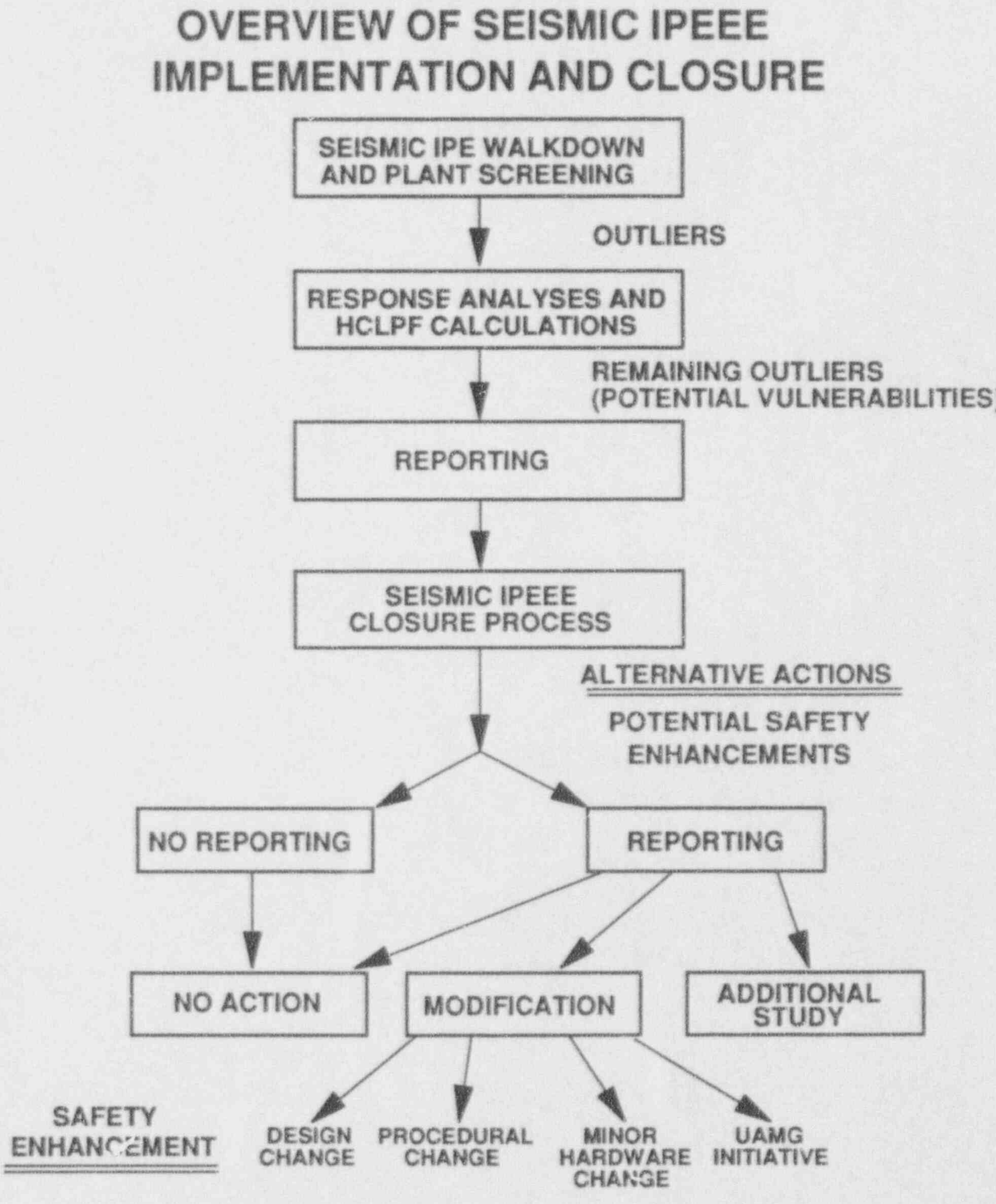

Figure 2-1. Diagram illustrating the overall seismic-IPEEE process.

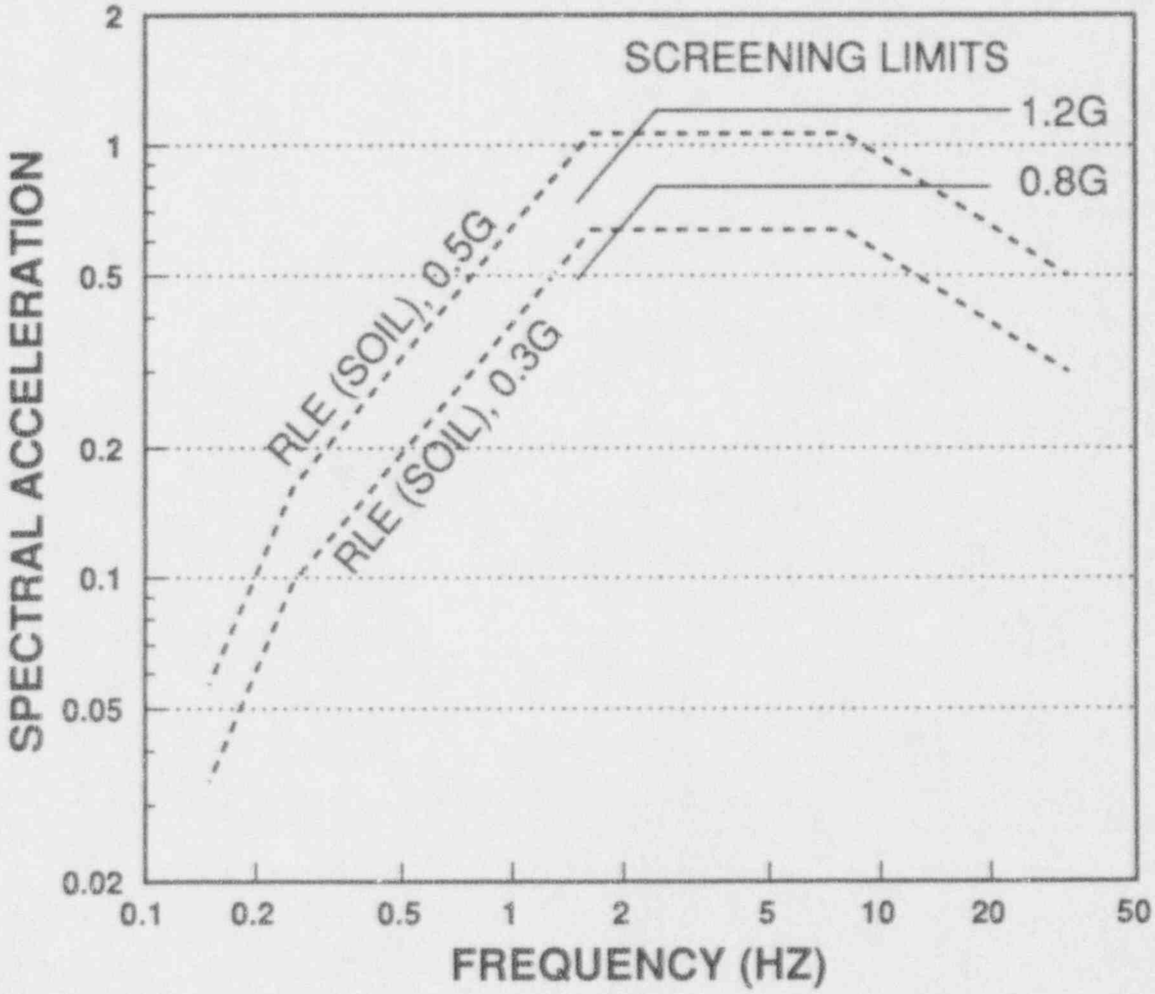

Figure 2-2. Spectral screening limits for implementing SMA screening criteria, compared with RLE spectra (at 0.3g and 0.5g) used in seismic-IPEEE implementation.

Section 3
SUMMARY OF SEISMIC HAZARD RESULTS

This section provides a quick summary of the seismic hazard results, for the PVNGS site, which are used as inputs to the comparison procedures and RLE evaluation approach described later. The fundamental results are seismic hazard curves for PGA and for spectral acceleration at vibration frequencies of 25 Hz, 10 Hz, 5 Hz, 2.5 Hz, and 1 Hz. From these curves, ground-motion spectra for uniform probabilities of exceedance (i.e., uniform hazard spectra) have been derived. Both hazard curves and uniform hazard spectra (UHS) are presented here to enable one to reproduce subsequent computations.

Complete documentation of the hazard study for the PVNGS site can be found in Reference (1). To facilitate subsequent analyses and comparisons [particularly for determining probabilities of exceedance of reference spectra (e.g., NUREG/CR-0098 and design bases)], ground-motion amplitudes have been converted, in the present study, from spectral velocities to spectral accelerations.

3.1 HAZARD-CURVE RESULTS

Data presented in Tables 3-1 to 3-6 provide the basis for constructing seismic hazard curves (annual frequencies of exceedance as a function of ground-motion amplitude) for peak acceleration and spectral acceleration at vibration frequencies of 25, 10, 5, 2.5, and 1 Hz. For various amplitudes of each of these ground-motion measures, the hazard data consist of the following statistics: mean, 15th fractile, median (50th fractile) and 85th fractile. Plots of the actual hazard curves for these statistics are shown in Figures 3-1 to 3-6.

3.2 UNIFORM HAZARD SPECTRA RESULTS

Table 3-7 presents ground-motion amplitudes corresponding to annual exceedance probability levels of 10^{-3}, 2×10^{-4}, 10^{-4}, and 10^{-5} Results are provided for the same set of hazard statistics described above.

Plots of the mean, 15th-fractile, median, and 85th-fractile UHS, for the above-referenced annual probability levels, are presented in Figures 3-7 to 3-10; separate graphs are shown for the different probability levels. In addition, Figure 3-11 shows, on one graph, the median UHS results for all probability levels.

3.3 RELEVANT ASPECTS OF THE PVNGS HAZARD ANALYSIS

For PVNGS to qualify as a 0.3g plant for IPEEE implementation, NUREG-1407 specifies that the seismic hazard at the PVNGS site should be similar to the hazard at sites in the central and eastern U.S. that belong to the 0.3g bin. For comparison purposes, there are available two separate studies of seismic hazard for plants in the central and eastern U.S.: the LLNL hazard study and the EPRI hazard study (2,3). In order to establish a meaningful comparison among hazard results, it is critical that similar study methods have been implemented in the development of all results. Consequently, the hazard analysis procedure for the PVNGS site must resemble, as closely as possible, the methodology developed in one of these major studies (LLNL or EPRI).

As discussed in Reference (1), the procedures employed in the hazard analysis are substantially similar to those comprising the EPRI seismic hazard methodology (4). The analysis was conducted in such a manner to establish a consistent basis for comparison of the PVNGS hazard results with the EPRI results for plants in the central and eastern United States. The soil amplification factors used in the PVNGS hazard analysis were different from those used (based on very general soil categorizations) in the EPRI hazard study of 58 sites (2); this difference was necessary as the general soil categorizations were judged to be inadequate (inapplicable) in characterizing the conditions at the PVNGS site. Nonetheless, the methods and format used in developing and describing site-specific soil amplification factors for the PVNGS site are very similar to those implemented in the EPRI hazard study.

Because the EPRI hazard study was undertaken specifically for plants east of the Rocky Mountains, but the PVNGS site is located in the Western U.S., one would expect some inherent differences in characterization of certain parameters in the analyses. For instance, the models and parameters for attenuation of ground motion differ necessarily to account for expected differences in ground-motion propagation for locations in the western versus eastern U.S. Despite these unavoidable differences, however, the hazard analysis for the PVNGS site is a state-of-the-art study representative of an EPRI analysis. In other words, it is believed that if the Palo Verde site were included in the original EPRI study, results would have been subtantially comparative to those obtained in Reference (1) [i.e., those used in this study].

Generally speaking, the LLNL hazard results for plants in the central and eastern U.S. are notably greater than those obtained from the EPRI hazard study. (Recent preliminary results of a revised LLNL assessment of seismic hazard suggest that new LLNL results will ultimately become more consistent with the existing EPRI results. The greatest agreement in results is expected to be seen for the median and 85th-fractile hazards. The LLNL revised

mean estimates of hazard are still likely to be substantially greater than corresponding EPRI results, by factors of about 2 to 5). It can be expected, therefore, that (comparatively speaking) the PVNGS hazard results will be generally lower relative to the LLNL hazard values than to the EPRI hazard numbers. Consequently, it would be inappropriate to compare the present PVNGS results with the LLNL hazard results.

3.4 REFERENCES

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Table 3-1

ANNUAL PROBABILITY OF EXCEEDANCE FOR PEAK GROUND ACCELERATION: PALO VERDE SITE (SOIL)

Peak Ground Acceleration (g)	Annual Exceedance Probabilities for:			
		Percentiles		
	Mean	15th	50th	85th
0.010	3.62E-02	2.07E-03	2.24E-02	7.24E-02
0.020	7.34E-03	9.33E-04	4.90E-03	1.48E-02
0.051	1.04E-03	2.69E-04	6.61E-04	1.86E-03
0.071	5.52E-04	1.45E-04	3.55E-04	9.33E-04
0.102	2.92E-04	7.76E-05	1.78E-04	5.01E-04
0.153	1.40E-04	3.39E-05	8.91E-05	2.51E-04
0.204	7.76E-05	1.48E-05	4.79E-05	1.35E-04
0.306	2.78E-05	3.47E-06	1.48E-05	4.96E-05
0.509	4.71E-06	1.35E-07	1.68E-06	9.12E-06
1.019	2.78E-07	8.13E-10	2.57E-08	3.80E-07

Table 3-2

ANNUAL PROBABILITY OF EXCEEDANCE FOR 25-HZ SPECTRAL ORDINATES (VELOCITY AND ACCELERATION): PALO VERDE SITE (SOIL)

Spectral Velocity (cm/sec)	Spectral Acceleration (g)	Annual Exceedance Probabilities for:			
			Percentiles		
		Mean	15th	50th	85th
0.03	0.005	1.90E-01	6.46E-03	1.55E-01	3.55E-01
0.06	0.010	4.32E-02	2.63E-03	3.16E-02	8.32E-02
0.10	0.016	1.39E-02	1.41E-03	9.77E-03	2.95E-02
0.20	0.032	3.03E-03	6.17E-04	2.00E-03	5.62E-03
0.50	0.080	5.06E-04	1.35E-04	3.31E-04	8.71E-04
1.00	0.160	1.42E-04	3.16E-05	8.91E-05	2.51E-04
2.00	0.320	2.58E-05	3.02E-06	1.38E-05	4.79E-05
5.00	0.800	9.87E-07	6.03E-09	1.55E-07	1.51E-06
7.00	1.120	2.73E-07	3.31E-10	1.70E-08	3.80E-07
10.00	1.600	6.29E-08	1.05E-11	1.07E-09	5.89E-08
15.00	2.401	1.02E-08	4.79E-14	2.85E-11	5.62E-09
20.00	3.201	2.50E-09	1.95E-29	1.62E-12	8.71E-10

Table 3-3

ANNUAL PROBABILITY OF EXCEEDANCE FOR 10-HZ SPECTRAL ORDINATES (VELOCITY AND ACCELERATION): PALO VERDE SITE (SOIL)

Spectral Velocity (cm/sec)	Spectral Acceleration (g)	Annual Exceedance Probabilities for:			
			Percentiles		
		Mean	15th	50th	85th
0.03	0.002	5.74E-01	7.94E-03	3.31E-01	9.33E-01
0.06	0.004	3.18E-01	4.27E-03	1.02E-01	7.59E-01
0.10	0.006	1.74E-01	2.82E-03	4.17E-02	4.07E-01
0.20	0.013	5.47E-02	1.51E-03	1.38E-02	1.18E-01
0.50	0.032	7.85E-03	7.59E-04	3.72E-03	1.59E-02
1.00	0.064	1.81E-03	3.55E-04	1.15E-03	3.24E-03
2.00	0.128	5.29E-04	1.18E-04	3.31E-04	8.71E-04
5.00	0.320	9.39E-05	9.77E-06	4.79E-05	1.78E-04
7.00	0.448	3.88E-05	1.00E-06	1.48E-05	7.24E-05
10.00	0.640	1.30E-05	5.50E-08	3.24E-06	2.57E-05
15.00	0.960	3.13E-06	2.63E-09	5.37E-07	5.43E-06
20.00	1.280	1.07E-06	3.43E-10	1.26E-07	1.74E-06

Table 3-4

ANNUAL PROBABILITY OF EXCEEDANCE FOR 5-HZ SPECTRAL ORDINATES (VELOCITY AND ACCELERATION): PALO VERDE SITE (SOIL)

Spectral Velocity (cm/sec)	Spectral Acceleration (g)	Annual Exceedance Probabilities for:			
			Percentiles		
		Mean	15th	50th	85th
0.15	0.005	4.10E-01	6.46E-03	2.88E-01	8.71E-01
0.50	0.016	5.75E-02	2.14E-03	3.16E-02	1.18E-01
1.00	0.032	1.46E-02	1.07E-03	7.94E-03	3.39E-02
2.00	0.064	3.30E-03	5.01E-04	2.00E-03	6.92E-03
5.00	0.160	5.27E-04	1.26E-04	3.31E-04	9.33E-04
7.00	0.224	2.88E-04	6.76E-05	1.78E-04	5.01E-04
10.00	0.320	1.51E-04	2.75E-05	8.32E-05	2.69E-04
15.00	0.480	6.59E-05	8.51E-06	3.16E-05	1.18E-04
20.00	0.640	3.26E-05	1.93E-06	1.29E-05	6.31E-05
30.00	0.960	9.63E-06	8.32E-08	2.29E-06	1.82E-05
50.00	1.600	1.53E-06	5.75E-10	1.26E-07	2.29E-06
100.00	3.201	1.07E-07	7.59E-13	1.27E-09	9.55E-08

Table 3-5

ANNUAL PROBABILITY OF EXCEEDANCE FOR 2.5-HZ SPECTRAL ORDINATES (VELOCITY AND ACCELERATION): PALO VERDE SITE (SOIL)

Spectral Velocity (cm/sec)	Spectral Acceleration (g)	Annual Exceedance Probabilities for:			
			Percentiles		
		Mean	15th	50th	85th
0.15	0.002	5.93E-01	2.95E-02	5.01E-01	9.33E-01
0.50	0.008	1.35E-01	4.42E-03	9.55E-02	2.88E-01
1.00	0.016	4.63E-02	1.62E-03	2.95E-02	1.10E-01
2.00	0.032	1.24E-02	6.61E-04	6.24E-03	2.95E-02
5.00	0.080	1.65E-03	1.91E-04	7.08E-04	3.24E-03
7.00	0.112	7.70E-04	1.10E-04	4.07E-04	1.41E-03
10.00	0.160	3.56E-04	5.89E-05	1.78E-04	6.17E-04
15.00	0.240	1.57E-04	2.75E-05	8.32E-05	2.69E-04
20.00	0.320	8.96E-05	1.38E-05	4.79E-05	1.66E-04
30.00	0.480	3.80E-05	3.72E-06	1.82E-05	6.76E-05
50.00	0.800	9.75E-06	2.34E-07	3.02E-06	1.70E-05
100.00	1.600	9.17E-07	2.00E-09	1.18E-07	1.32E-06

Table 3-6

ANNUAL PROBABILITY OF EXCEEDANCE FOR 1-HZ SPECTRAL ORDINATES (VELOCITY AND ACCELERATION): PALO VERDE SITE (SOIL)

Spectral Velocity (cm/sec)	Spectral Acceleration (g)	Annual Exceedance Probabilities for:			
			Percentiles		
		Mean	15th	50th	85th
0.15	0.001	7.07E-01	8.32E-02	6.17E-01	9.33E-01
0.50	0.003	1.96E-01	1.05E-02	1.66E-01	4.07E-01
1.00	0.006	8.49E-02	2.82E-03	6.76E-02	1.78E-01
2.00	0.013	3.22E-02	8.13E-04	2.40E-02	6.76E-02
5.00	0.032	5.84E-03	1.78E-04	2.46E-03	1.38E-02
7.00	0.045	2.70E-03	1.02E-04	1.00E-03	6.46E-03
10.00	0.064	1.11E-03	5.50E-05	3.55E-04	2.46E-03
15.00	0.096	3.78E-04	2.09E-05	1.35E-04	7.08E-04
20.00	0.128	1.74E-04	8.51E-06	6.31E-05	3.09E-04
30.00	0.192	5.89E-05	2.14E-06	2.09E-05	1.10E-04
50.00	0.320	1.48E-05	2.04E-07	4.57E-06	2.75E-05
100.00	0.640	1.68E-06	2.14E-09	2.19E-07	2.63E-06

Table 3-7

SPECTRAL ACCELERATIONS FOR VARIOUS EXCEEDANCE PROBABILITIES: PALO VERDE SITE (SOIL)

Exceedance Probability	Statistic or Percentile	Frequency (Hz)					
		PGA	25	10	5	2.5	1
		Period (sec)					
		PGA	0.04	0.1	0.2	0.4	1
1×10^{-3}	Mean	0.052	0.056	0.089	0.116	0.100	0.067
	15	0.019	0.021	0.022	0.034	0.023	0.011
	50	0.042	0.046	0.069	0.091	0.069	0.045
	85	0.069	0.075	0.119	0.155	0.130	0.086
2×10^{-4}	Mean	0.126	0.133	0.214	0.274	0.213	0.122
	15	0.060	0.063	0.092	0.118	0.077	0.030
	50	0.096	0.104	0.163	0.210	0.152	0.081
	85	0.170	0.176	0.299	0.370	0.286	0.152
1×10^{-4}	Mean	0.180	0.185	0.310	0.392	0.302	0.158
	15	0.088	0.092	0.136	0.181	0.118	0.045
	50	0.143	0.151	0.226	0.294	0.218	0.108
	85	0.230	0.235	0.397	0.517	0.402	0.199
1×10^{-5}	Mean	0.410	0.418	0.690	0.948	0.793	0.363
	15	0.227	0.225	0.317	0.454	0.354	0.122
	50	0.335	0.342	0.491	0.680	0.569	0.246
	85	0.495	0.485	0.819	1.113	0.924	0.432

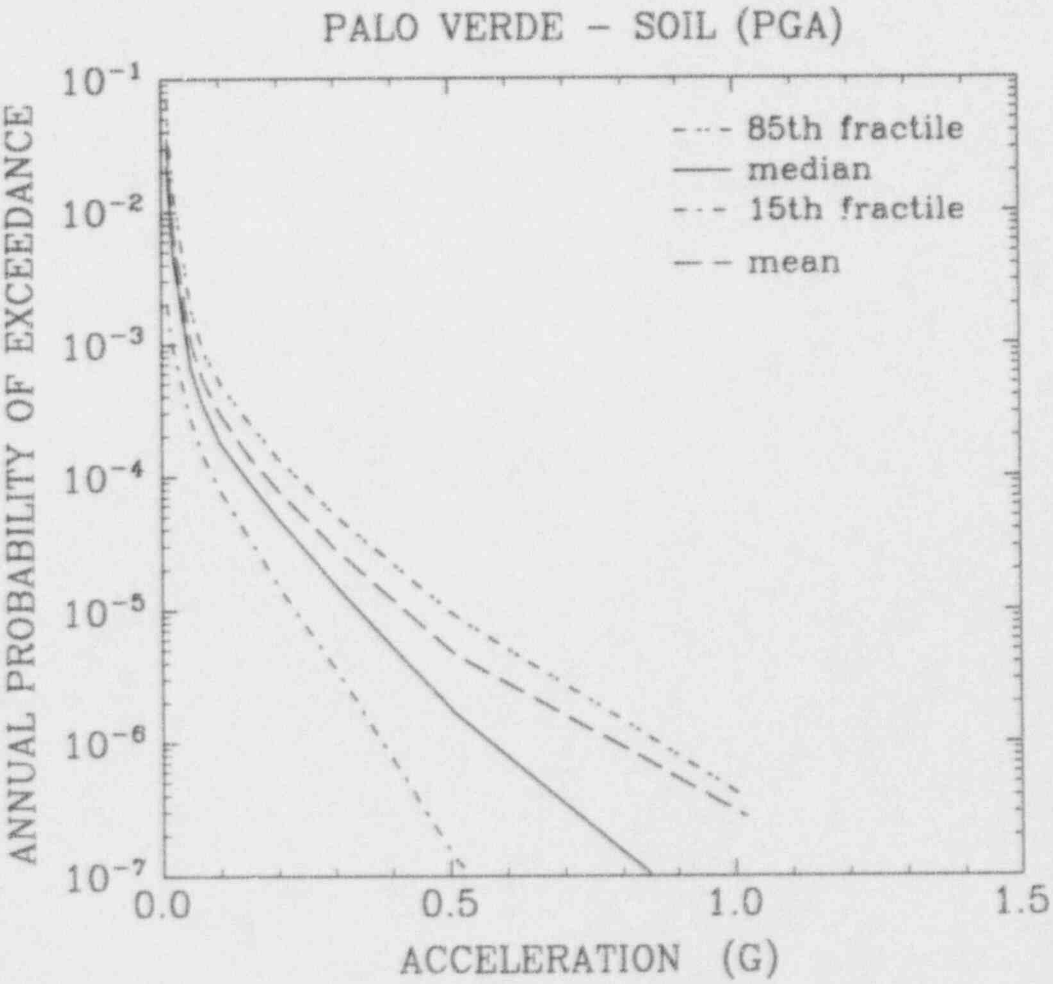

Figure 3-1. Mean, 15th-fractile, median, and 85th-fractile seismic hazard curves for peak ground acceleration; Palo Verde site (Soil).

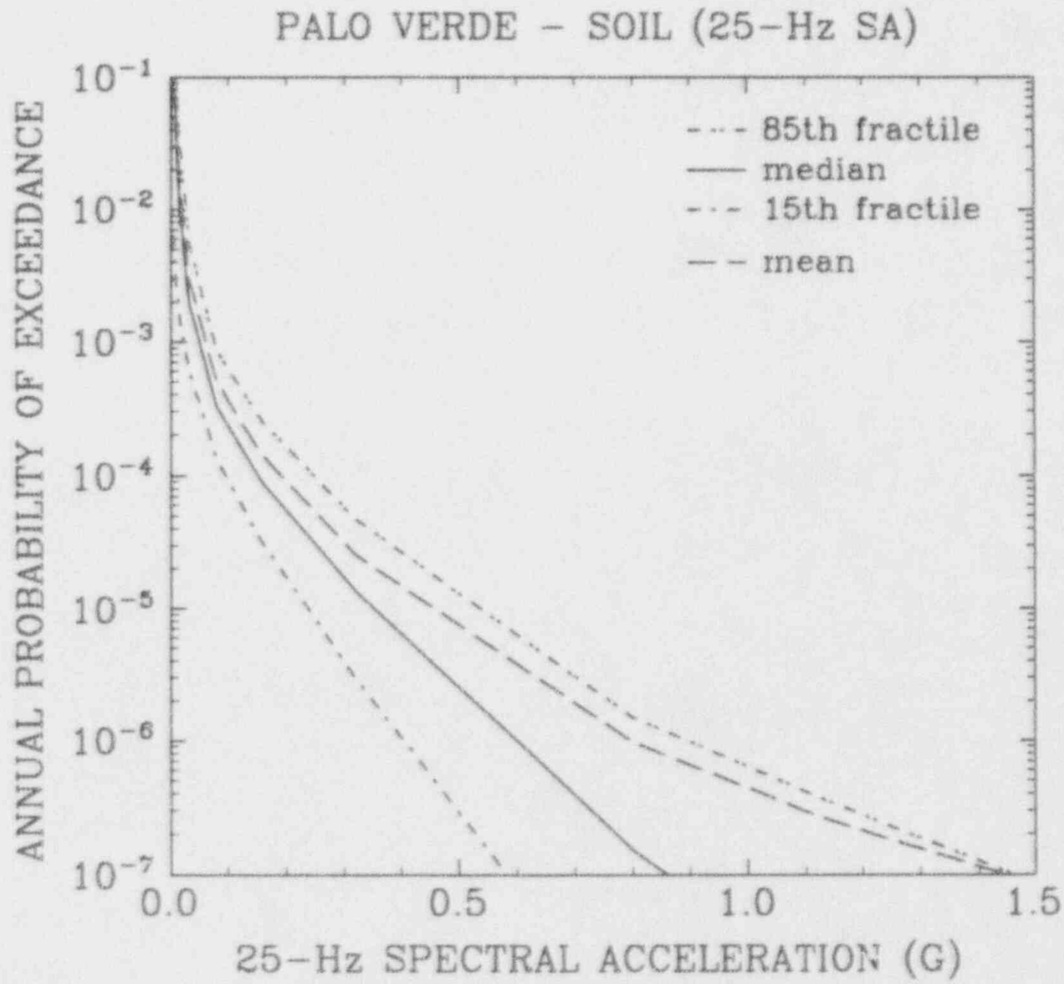

Figure 3-2. Mean, 15th-fractile, median, and 85th-fractile seismic hazard curves for 25-Hz spectral acceleration; Palo Verde site (Soil).

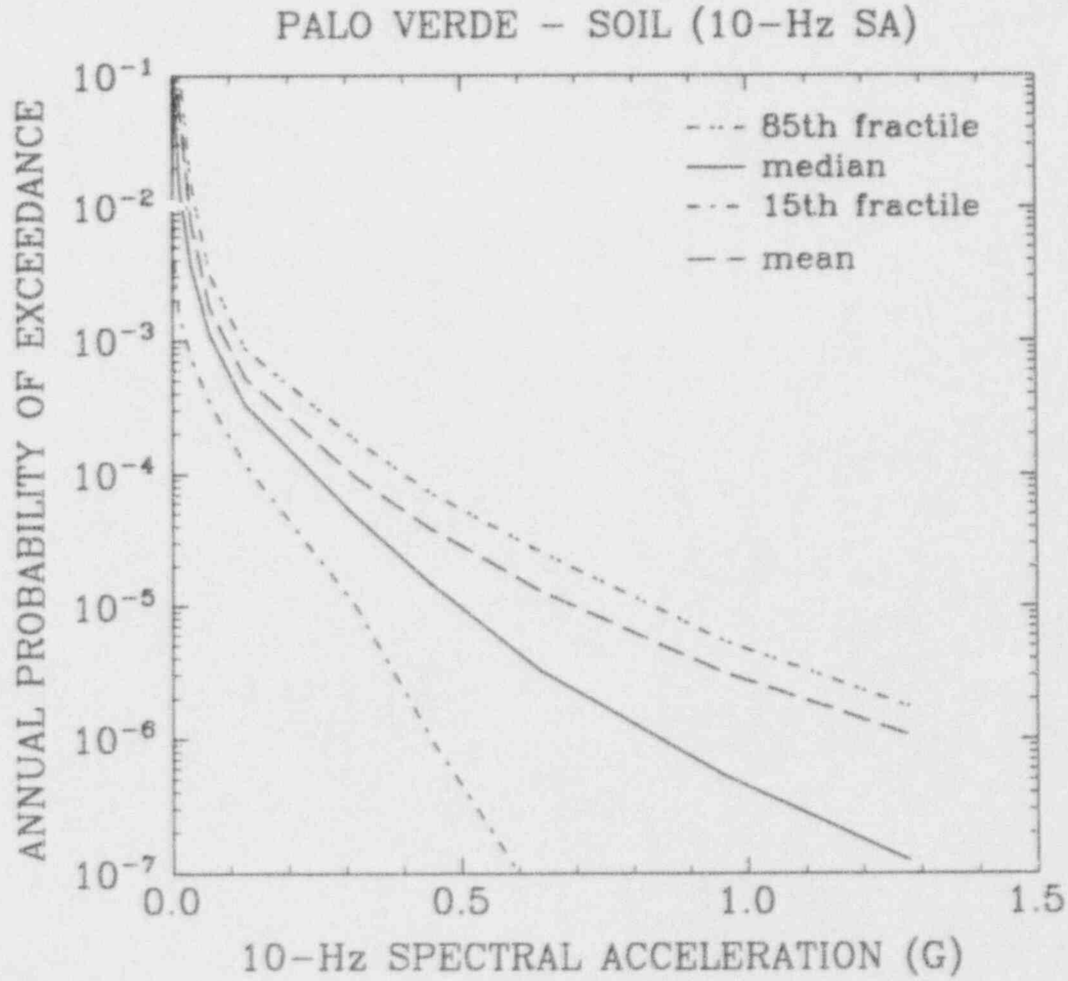

Figure 3-3. Mean, 15th-fractile, median, and 85th-fractile seismic hazard curves for 10-Hz spectral acceleration; Palo Verde site (Soil).

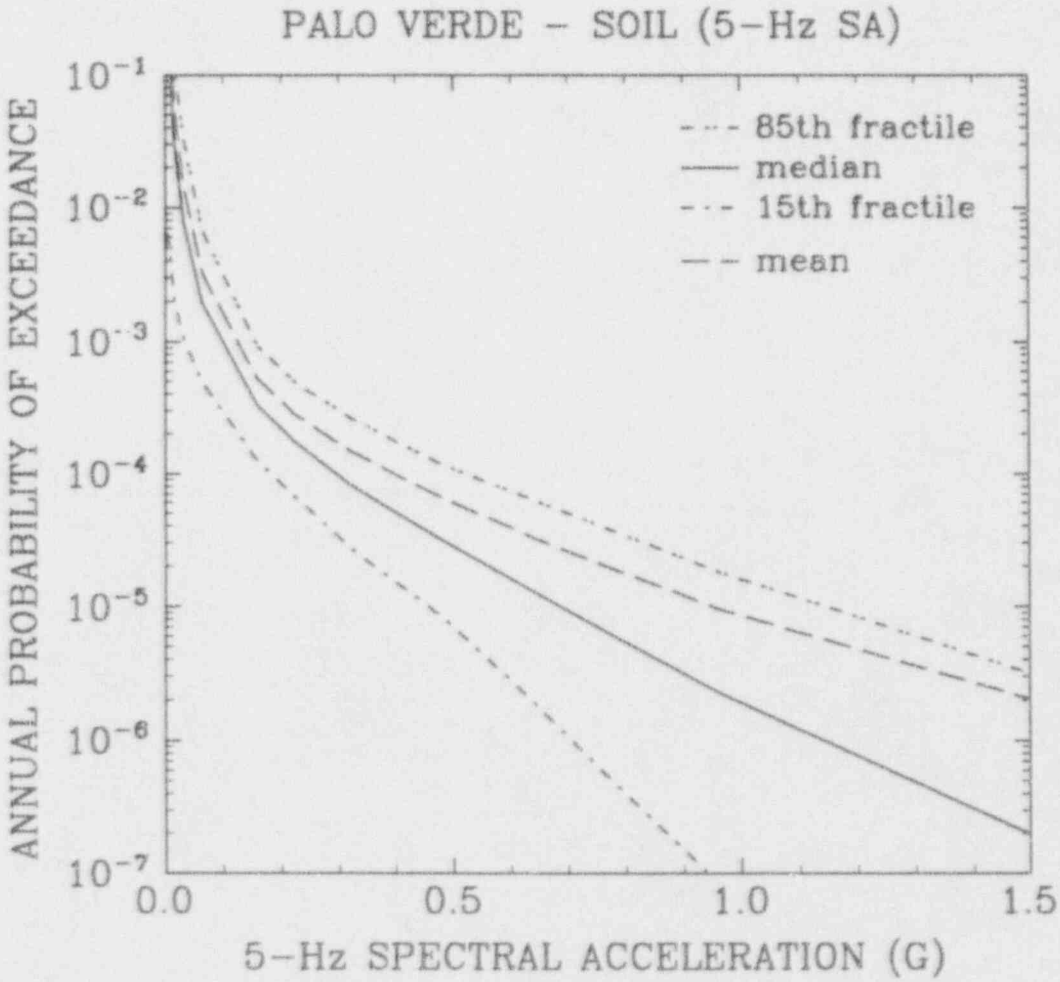

Figure 3-4. Mean, 15th-fractile, median, and 85th-fractile seismic hazard curves for 5-Hz spectral acceleration; Palo Verde site (Soil).

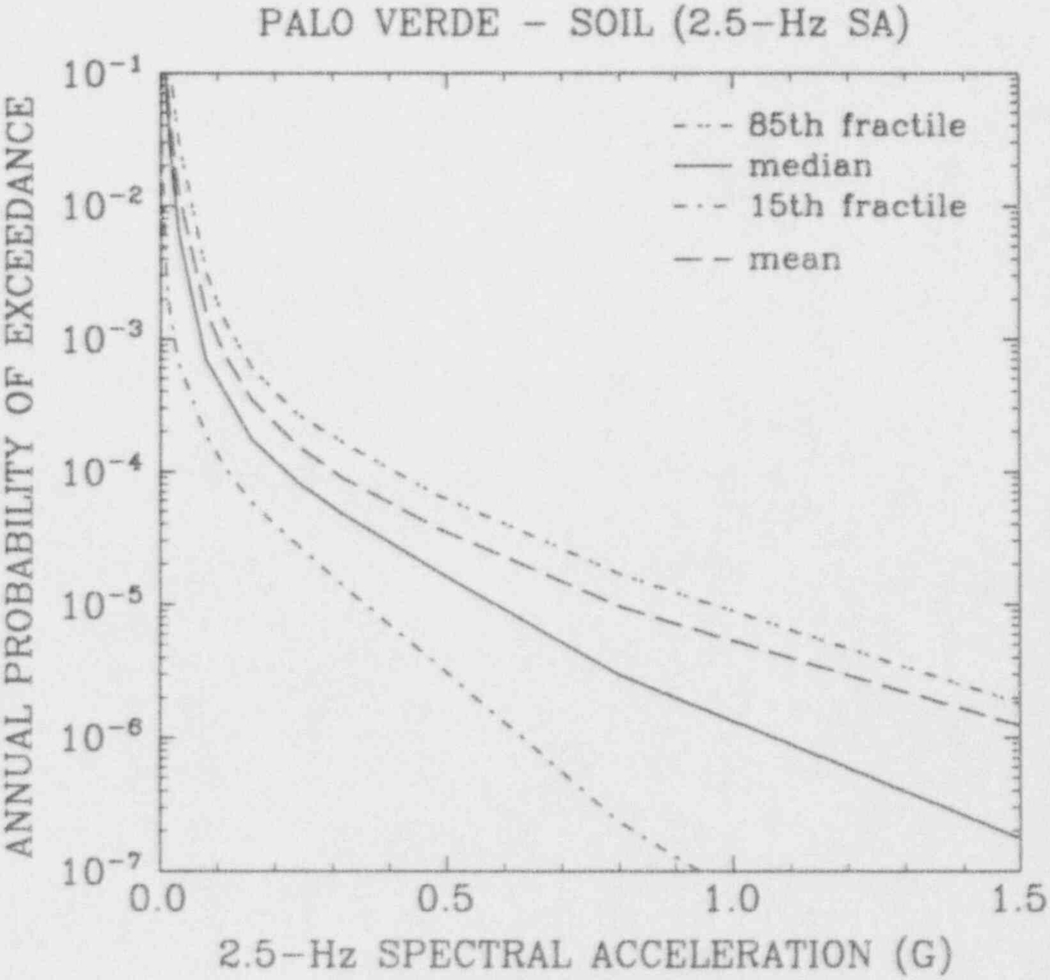

Figure 3-5. Mean, 15th-fractile, median, and 85th-fractile seismic hazard curves for 2.5-Hz spectral acceleration; Palo Verde site (Soil).

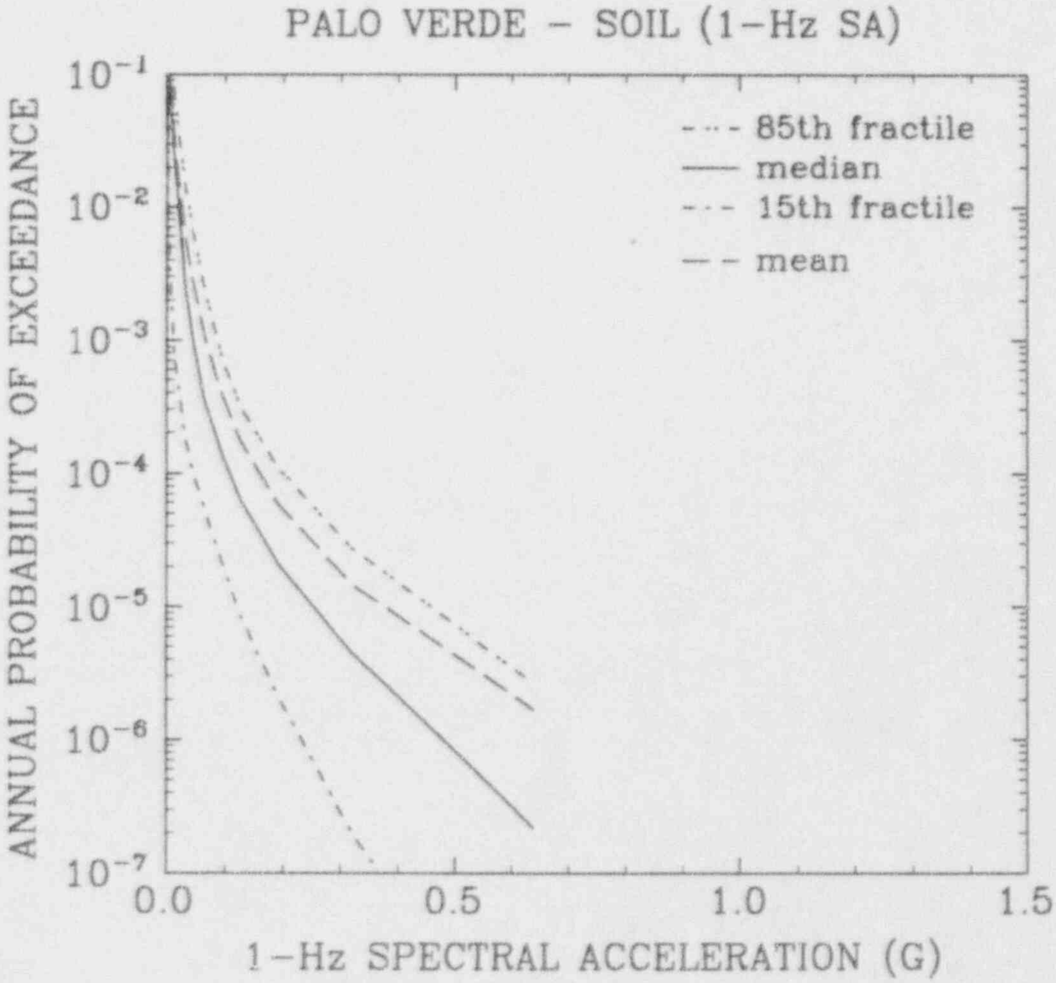

Figure 3-6. Mean, 15th-fractile, median, and 85th-fractile seismic hazard curves for 1-Hz spectral acceleration; Palo Verde site (Soil).

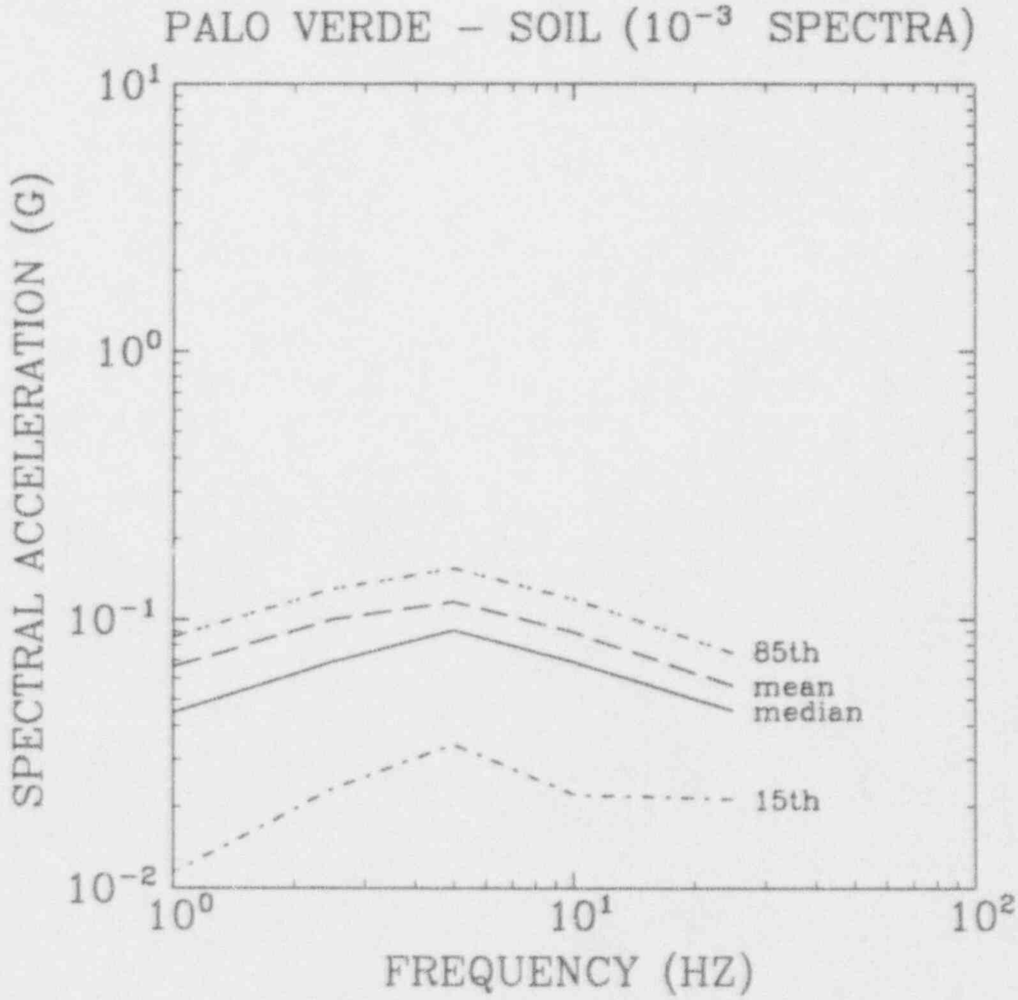

Figure 3-7. Mean, 15th-fractile, median, and 85th-fractile uniform seismic-hazard spectra for an annual exceedance frequency of 1×10^{-3}; Palo Verde site (Soil).

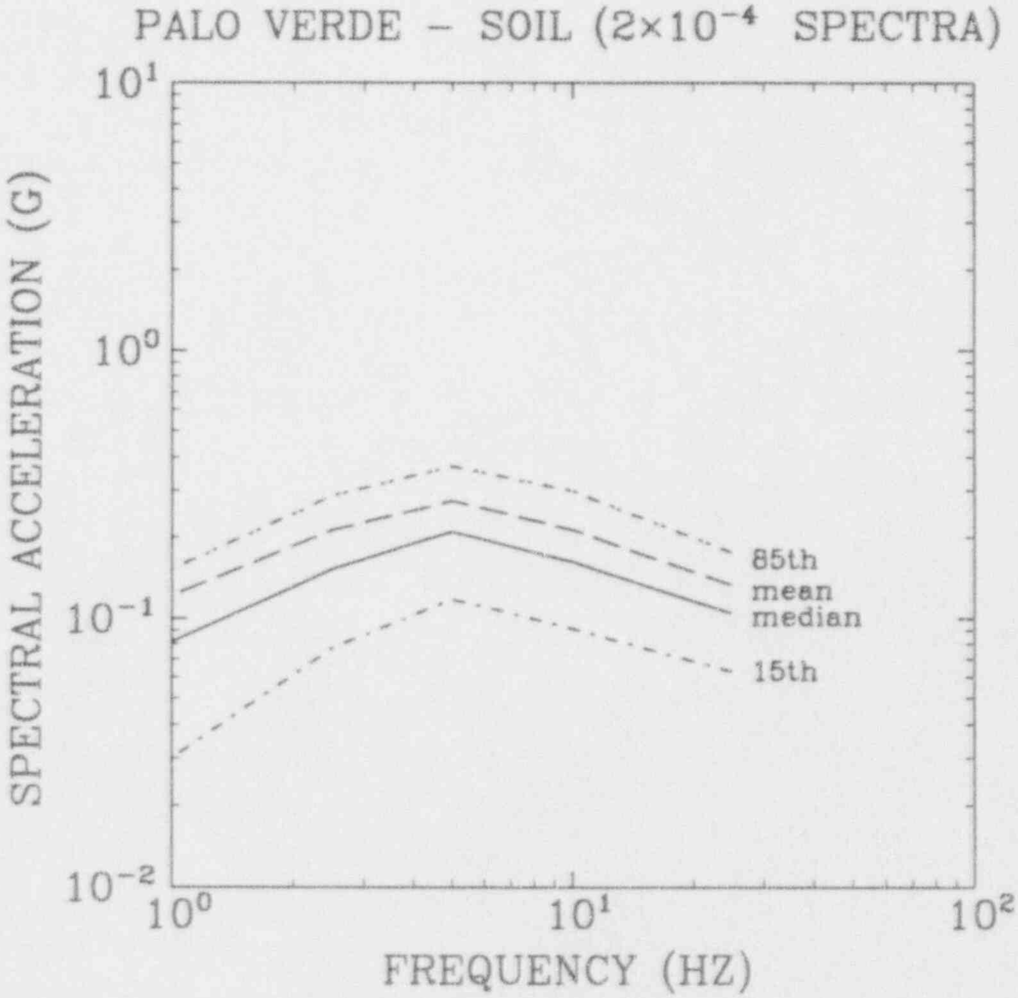

Figure 3-8. Mean, 15th-fractile, median, and 85th-fractile uniform seismic-hazard spectra for an annual exceedance frequency of 2×10^{-4}; Palo Verde site (Soil).

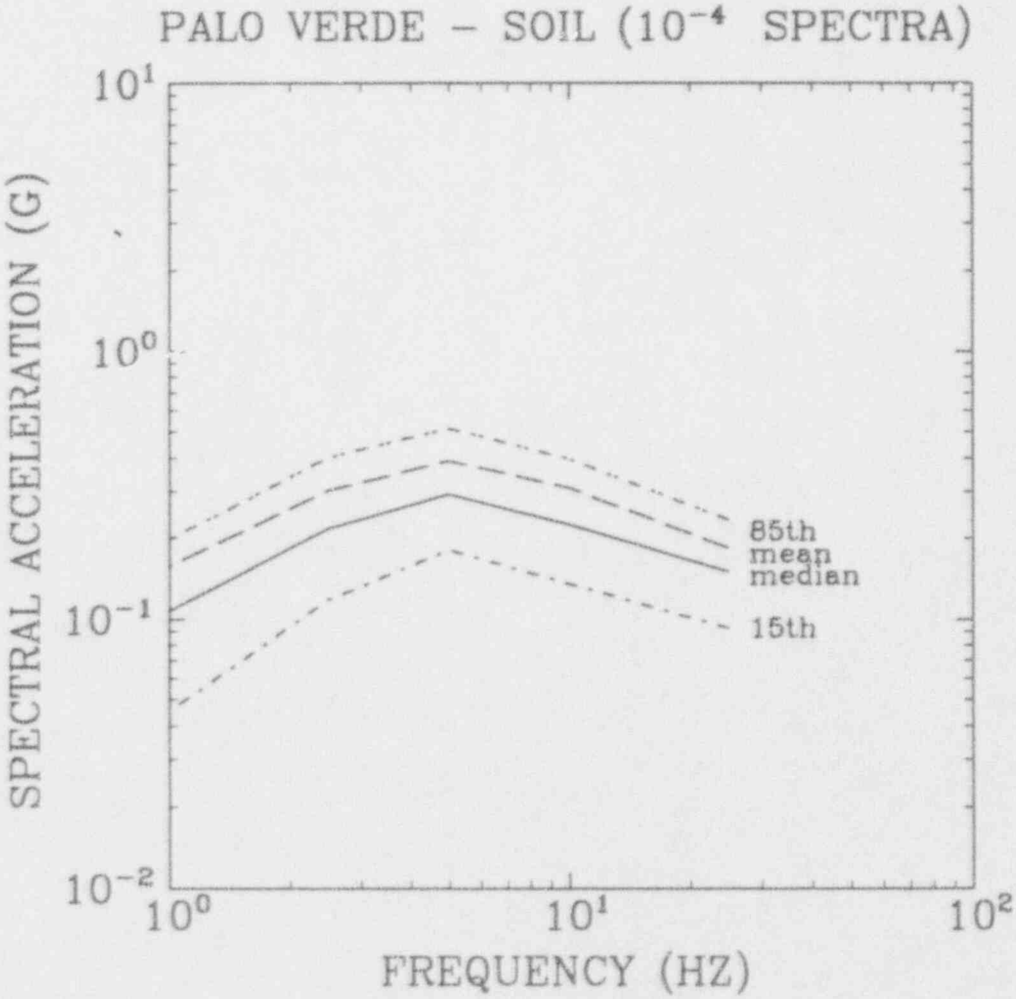

Figure 3-9. Mean, 15th-fractile, median, and 85th-fractile uniform seismic-hazard spectra for an annual exceedance frequency of 1×10^{-4}; Palo Verde site (Soil).

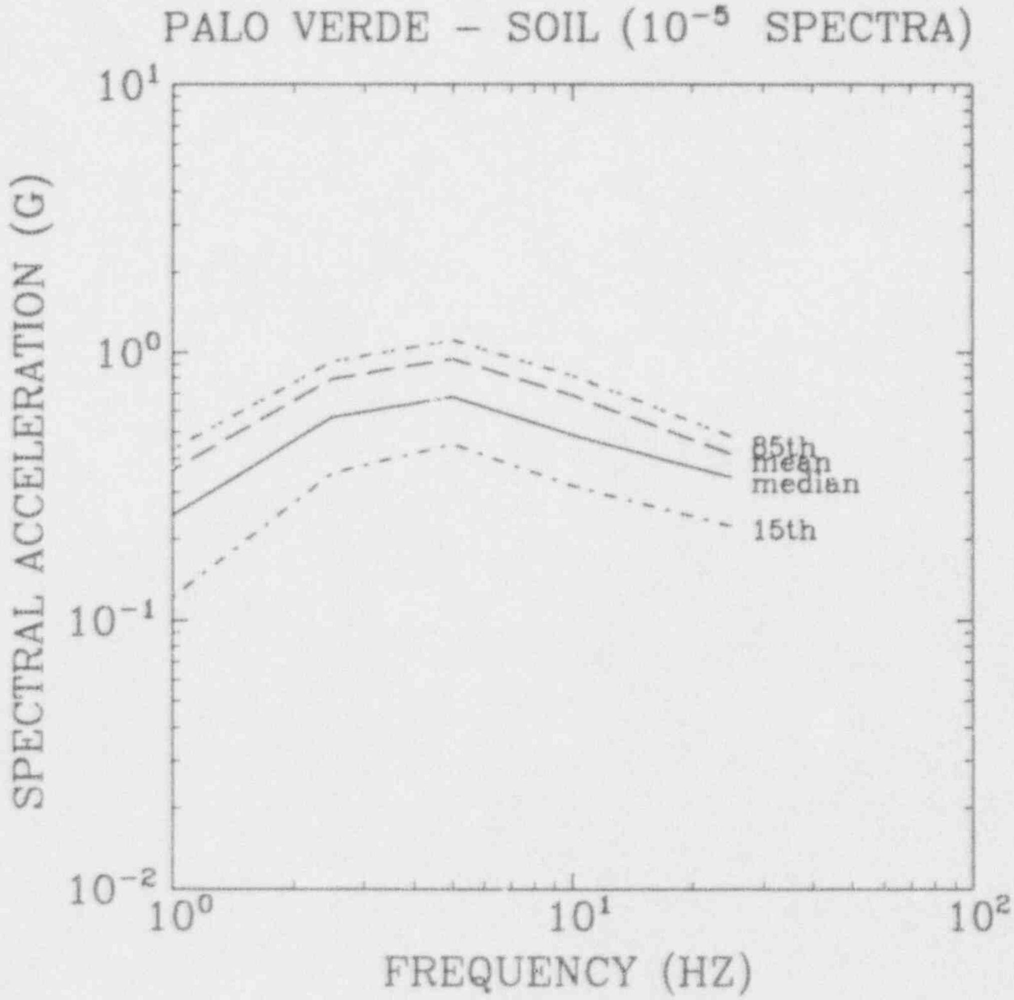

Figure 3-10. Mean, 15th-fractile, median, and 85th-fractile uniform seismic-hazard spectra for an annual exceedance frequency of 1×10^{-5}; Palo Verde site (Soil).

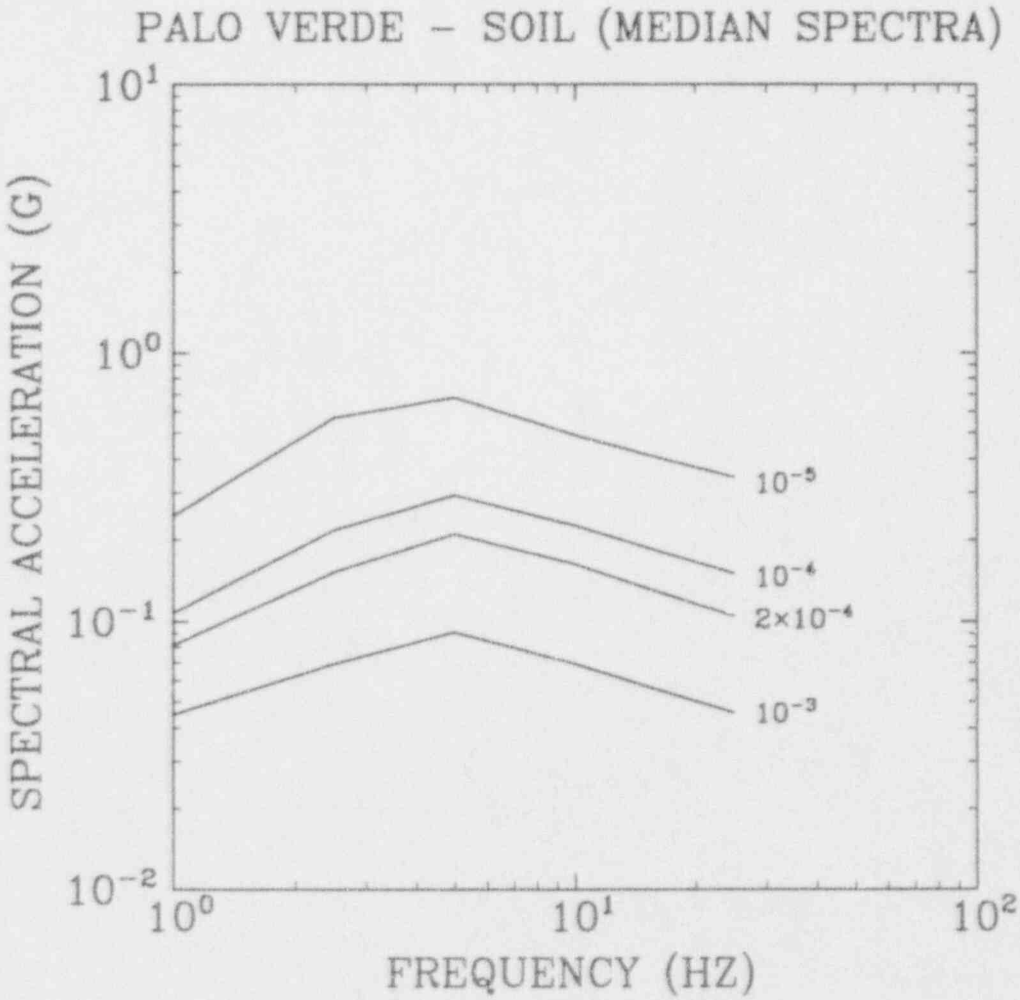

Figure 3-11. Median uniform seismic-hazard spectra for annual exceedance frequencies of 1×10^{-3}, 2×10^{-4}, 1×10^{-4}, and 1×10^{-5}; Palo Verde site (Soil).

Section 4
RLE EVALUATION APPROACH

This section summarizes the approaches, used for comparing seismic hazard results, which serve as a basis in developing a recommended RLE value at the PVNGS site. The justification for the procedures and comparisons employed is provided. An overview of specific aspects in NUREG-1407 (1) which pertain to plant binning is presented to demonstrate a consistent approach and basis in this report. The technical methods for computing hazard-based measures are clearly explained, to enable one to reproduce this study's results. And, the appropriate role of alternative hazard comparisons in developing RLE-related assessments is explained.

4.1 OVERVIEW OF RECOMMENDATIONS IN NUREG-1407

The general RLE evaluation approach discussed here follows closely the binning rationale and bases adopted in NUREG-1407 for RLE assessment. For the PVNGS site to be reassigned in the 0.3g review-level bin, NUREG-1407 requires simply that it be shown that the site hazard is similar to that at plants east of the Rocky Mountains that are found in the 0.3g bin.

Because, however, there are a variety of hazard statistics and an infinite set of combinations and comparisons that can be made with these, specific guidance on the comparison process proves useful in practical assessment. To achieve the greatest level of consistency with the basis for binning the central/eastern U.S. plants, the specific hazard statistics, weighting criteria, and binning philosophy used in NUREG-1407 are considered here. These aspects of the RLE evaluation process (characterized as they are presented in Appendix A of NUREG-1407) are discussed below:

- Comparison Procedure. Hazard comparisons are made using the mean, median, and 85th-fractile hazard statistics. As discussed in Section 3, the PVNGS seismic hazard results are compared with results of the EPRI hazard study (which utilized analysis methods substantially similar to the methods implemented to generate the PVNGS results) in order to make a determination of the appropriate RLE assignment for the

Palo Verde site. NUREG-1407 does not specify that a particular analysis procedure (EPRI, LLNL, or other) must be used to demonstrate similarity in seismic hazard. It is anticipated that the binning results achieved will be substantially robust with respect to the hazard methodology considered, so long as comparisons are made on a consistent and relative basis.

In addition, in its process for RLE binning of CEUS plants, NUREG-1407 required that EPRI and LLNL hazard studies must both support a RLE binning of 0.5g in order for a final RLE of 0.5g to be concluded. Specifically, if either the EPRI median hazard or the EPRI mean and 85th-fractile hazards led to a conditional RLE binning of 0.3g, then a 0.5g binning would not be concluded, regardless of the conditional RLE binnings derived from the LLNL results. In other words, the EPRI results alone were sufficient to preclude a final RLE binning of 0.5g. On the same basis, therefore, if relative comparisons of either the EPRI median or the EPRI mean and 85th-fractile results, with Palo Verde results, support a conditional RLE binning of 0.3g, then a final RLE binning of 0.5g cannot be concluded. Consequently, comparison among EPRI hazard results alone is sufficient to conclude whether or not a 0.3g RLE binning is appropriate for the Palo Verde site.

- Weighting Criteria. To facilitate developing conclusions from hazard comparisons, it is useful to establish a reasonable weighting of results for various vibration frequencies. In this manner, ambiguities related to variations in comparisons across spectral frequencies are removed. NUREG-1407 specifies that unit weights of 2/7th each should be assigned to the likelihoods of exceeding spectral response ordinates at 2.5, 5, and 10 Hz, whereas one-half unit weight should be assigned to the likelihood of exceeding the PGA. (Note, the weightings are applied to exceedance frequencies as opposed to ground-motion ordinates). The present study makes no representation that this method of frequency-dependent weighting is the most reasonable (many studies would suggest giving no weight to PGA). Nonetheless, to establish comparisons that are consistent with the basis used in defining the 0.3g bin, it has been considered appropriate to adopt the same weighting criteria here as used in NUREG-1407. (To demonstrate the robustness of conclusions, however, additional hazard weighting criteria and comparisons have been considered in this study, and are described more fully in Section 4.3).

- Spectral Shape. Comparisons of a single uniform hazard spectrum will not account for the range of exceedance frequencies, and variations with vibration frequency, that are expected to be meaningful to plant risk. A variety of UHS may be compared, or alternatively (to facilitate comparison), a relevant transformation of the hazard surface (a

three-dimensional function of vibration frequency and ground-motion amplitude) may be performed which does achieve an appropriate comparison that is roughly meaningful in terms of contribution to plant risk. Selection of an appropriate ground-motion spectrum provides a simple basis for performing such a transformation.

Because the seismic design process is used to establish capacities of major plant components, and because the probability of exceeding plant capacity is relevant to plant risk, it would appear appropriate that the seismic design-basis spectrum be chosen for the hazard transformation. In fact, such a means for characterizing hazard results has been proposed (2,3). An alternative viewpoint is that the seismic design level may generally have little significance on plant capacity (and risk) due to dominance of spurious conditions and unanticipated outliers that are not directly impacted by the magnitude of the design level. In this case, a target plant HCLPF capacity may be considered to be a more appropriate hazard-transformation basis. Although plant-specific target HCLPFs or acceptance levels have not been proposed in NUREG-1407, the NUREG/CR-0098 (median, 5%-damped) spectrum anchored to 0.3g serves as a preliminary basis for characterizing a target and/or expected plant capacity. In fact, NUREG-1407 does specify that this spectrum be used for performing hazard transformations in developing probability of exceedance characterizations used as a basis for the major grouping of plants into 0.5g and 0.3g bins. For the plants that fall within the 0.3g bin on this basis, however, the design-basis spectrum is subsequently used for hazard transformation in developing exceedance-probability characterizations for sub-grouping the plants into full-scope and focused-scope categories.

A similar approach is taken in this study. That is, similarity in comparisons of probabilities of exceeding the NUREG/CR-0098 (median, 5%-damped) spectrum is used as a basis for delineating whether or not a 0.3g RLE assessment at the PVNGS site would be appropriate. Provided that a favorable basis for the 0.3g RLE evaluation is indicated, then similarity in probabilities of exceeding plant design basis is used to decide whether or not a focused-scope categorization is justified. NUREG-1407 does not allow the implementation of focused-scope procedures, on an exclusive basis, for IPEEE review at the Palo Verde station. Yet, if a favorable comparison for focused-scope categorization is indicated, certain applications of focused-scope methods may be appropriate, as so judged by the IPEEE Seismic Review Team after performing a full-scope analysis of one of the reactor units.

- Specific Binning Procedure. Nine separate hazard measures (three hazard statistics each for the LLNL five-expert, LLNL four-expert, and EPRI studies) were used

in NUREG–1407 as binning criteria. Conditional binnings were obtained for each of these nine measures based on a grouping/clustering methodology employed in NUREG–1407. Final binning was based on a consistency analyses of the nine distinct groupings; consistency criteria considered agreement among all of the three hazard studies and agreement between the median and either the mean or 85th-fractile statistic. For a final binning assignment of 0.5g, all consistency criteria had to be satisfied. For instance, if a 0.5g conditional binning assignment was indicated for all criteria except the EPRI median, a plant would remain in the 0.3g bin; conclusions on binning had to be clearly supported by all hazard studies.

For the present case where results of EPRI hazard analyses are compared, the above binning approach would imply that conditional assignments of 0.5g must be indicated for all three criteria (mean, median, and 85th-fractile results) in order for a final RLE binning of 0.5g to be clearly supported. In other words, if only one of the criteria indicated a 0.3g conditional assignment, then that assignment would govern the final binning (of 0.3g).

In the present study, a formal conditional binning assessment (as that used in NUREG–1407) is not undertaken. Although including the PVNGS results in the original binning procedure would have effected the basis for clustering or grouping plants, no such explicit impact on the binning delineations is considered here. As a surrogate (and simpler) approach to the conditional binning based on clustering, this study assumes that the range of composite exceedance probabilities defined by the 0.3g plants defines general reference limits for making conditional assignments to a 0.3g or 0.5g bin. Hence, if a composite exceedance probability for a particular hazard statistic fell above the upper limit of similar results for the 0.3g plants, then a conditional assignment of 0.5g would be indicated for that hazard statistic. Because (for a variety of reasons) the binning delineations are not precise, a variation on the order of a few percent above the upper limit would not be considered significant.

- Subsequent Binning Evaluations. To confirm that the absolute level of hazard was sufficiently high to warrant inclusion in the 0.5g bin, a subsequent "sanity check" was included in the NUREG–1407 binning evaluation. In this confirmation check, it was assumed that a 0.5g binning assessment would be supported if: (1) the mean or 85th-fractile (composite) annual likelihood of exceeding the 0.3g spectrum from all hazard studies was 10^{-4} or greater, and (2) the median (composite) annual likelihood of exceeding the 0.3g spectrum from all hazard studies was 10^{-5} or greater.

For the present RLE evaluation approach, this check implies that the median composite probability of exceeding the 0.3g NUREG/CR–0098 spectrum must be greater that the value of 10^{-5} and either the corresponding mean or 85th-fractile composite probability must also exceed the value of 10^{-4} to confirm a 0.5g assignment. Stated in an alternative way, if both the mean and 85th-fractile values are less that 10^{-4}, but the median value is greater than 10^{-5}, then an RLE assessment of 0.5g is not clearly supported.

The above aspects of the NUREG–1407 procedure help to better define consistent avenues to follow in performing seismic hazard comparisons for RLE assessment. The use of specific, reasonable hazard statistics and hazard-transformation procedures helps focus comparisons in a meaningful way.

4.2 OVERVIEW OF INDUSTRY RECOMMENDATIONS

Industry recommendations for selection of a seismic-IPEEE review type are provided in the report EPRI NP–7498. The overall approach is somewhat similar to that specified in the NUREG–1407 analyses. In particular, the use of composite probabilities of exceeding seismic design levels is recommended in selecting among full-scope and focused-scope review alternatives.

The overall philosophy and bases for review-level selection recommended in EPRI NP–7498 have influenced the guidelines developed in NUREG–1407 and have served as background for the present study. The approach does not describe specific methods that would be applicable for distinguishing a 0.5g review level. Hence, no further specific consideration of these guidelines is required.

4.3 CALCULATION OF HAZARD-BASED MEASURES

Although the RLE evaluation and plant binning procedures of NUREG–1407 are based on the assessment of composite probabilities of exceeding the NUREG/CR–0098 spectrum, there are a variety of other hazard measures that have been considered in this study. Calculated hazard measures include: the composite measure of exceedance probability (where the result for 2.5 Hz, 5.0 Hz, and 10.0 Hz is each given two-sevenths [2/7] weight and the result for PGA is given the remaining one-seventh [1/7] weight); an alternate composite measure of exceedance probability (where the result for 2.5 Hz, 5.0 Hz, and 10.0 Hz is each given one-third [1/3] weight and the result for PGA is given zero weight); the peak probability of exceeding the NUREG/CR–0098 spectrum over the range of 2 to 10 Hz; the average value

of exceedance probability over the same frequency range; the peak spectral acceleration over the frequency range of 2 to 10 Hz; and the average value of spectral acceleration over the same frequency range. The basis and significance for use of each of these scalar measures is discussed below.

4.3.1 Composite Exceedance Probabilities

As identified in Section 4.1, the primary hazard-based measures required for subsequent comparisons and RLE evaluation consist of composite probabilities of exceeding the 0.3g NUREG/CR-0098 spectra and composite probabilities of exceeding plant seismic design levels. As illustrated in Figures 4-1 and 4-2, the calculation of these measures is straightforward. Whether the 0.3g NUREG/CR-0098 spectrum, the design-basis spectrum, or some other ground-motion spectrum is used as the hazard-transformation basis, the approach for obtaining the probability measures is identical. In all cases, we assume that a reference spectrum has been obtained for converting to probabilities.

As shown in Figures 4-1, the first step in obtaining probabilities is to overlay a set of uniform hazard spectra (mean, median, or 85th fractile) on the reference spectrum and interpolate between UHS curves for ground-motion ordinates at various vibration frequencies. The vibration frequencies to consider include the union of frequencies defining the UHS curves and the reference spectrum, to insure that all distinct segments of the subsequent probability spectra are defined. (Although not shown in Figure 4-1, the interpolation of probabilities should also be performed for PGA). In addition, the interpolation (at given vibration frequency) assumes a linear variation in the logarithm of hazard versus the logarithm of ground-motion ordinates.

The next step is to construct a probability spectrum from the interpolated results at the various vibration frequencies. By obtaining such probability spectra for several sites, comparisons can be readily made (as indicated in Step C of Figure 4-1). These comparisons are useful in indicating variations in hazard-based measures with vibration frequency. For purposes of binning comparisons and RLE evaluation, these spectral results must be converted to scalar or composite probabilities. The procedure for weighting the probability spectra to obtain composite-probability values is indicated in Figure 4-2.

The transformation of ground-motion spectra to composite probabilities occurs separately for mean, median, and 85th-fractile hazard statistics. For comparison purposes, the results are three plots for each type of ground-motion transformation; each plot presents (based on results for several sites) plant-to-plant values of composite probabilities for a given hazard statistic.

4.3.2 Alternate-Composite Exceedance Probabilities

It turns out that in weighting exceedance probabilities, the result for PGA can have a notable effect on the composite probability measure. The PGA, however, is known to be a relatively poor indicator of potential ground-motion effects on nuclear power plants (4), whereas the significant motion-frequency range for critical nuclear power plant structures and equipment is generally accepted to be roughly 2 to 10 Hz (2). For these reasons, it has been considered appropriate to define an alternate composite probability measure, for use in this study, that weights hazard results only in the 2.0 to 10 Hz frequency range. This alternate-composite probability measure is computed in the exact same manner as for the composite probability (as described in Figures 4-1 and 4-2) except that a weighting factor of zero is applied to the result for PGA, and a weighting factor of one-third (1/3) is applied to each of the results for 2.5 Hz, 5.0 Hz, and 10.0 Hz.

4.3.3 Peak Spectral Acceleration and Peak Exceedance Probabilities

Another type of hazard measure included in this study is based on the peak value, of exceedance probability or of uniform-hazard spectral acceleration, that occurs over the frequency range of 2 to 10 Hz. One significant justification for this hazard measure is the assumption that, plant fragility is equally sensitive within the frequency range of 2 to 10 Hz. This situation can occur if there are a number of components, each equally important in preventing plant failure, and each having a response frequency range that can lie uniformly at random within 2 to 10 Hz. In other words, the frequency band of dominant-risk components is broad, spanning the entire range of 2 to 10 Hz. Hence, the important point in this case is that plant failure is equally sensitive to response frequencies in the range of 2 to 10 Hz, so that plant risk is nearly certain to be dominated by (i.e., effected by) the peak measure of hazard over this frequency range.

The peak measure is simply obtained. From a uniform hazard spectrum, the peak spectral acceleration is found simply as the maximum value of the UHS plot between 2 and 10 Hz; from an exceedance-probability spectrum, the peak exceedance probability is found simply as the maximum ordinate on the plot between 2 and 10 Hz.

The evaluation of peak values occurs separately for mean, median, and 85th-fractile hazard statistics. For comparison purposes, the results are plots presenting (based on results for several sites) plant-to-plant values of peak exceedance probability or peak spectral acceleration, for a given hazard statistic.

4.3.4 Average Spectral Acceleration and Average Exceedance Probabilities

The remaining measure of hazard included in this study is based on the average value, of exceedance probability or of uniform-hazard spectral acceleration, taken over the frequency range of 2 to 10 Hz. One justification for this hazard measure is the assumption that plant fragility is sensitive only within a narrow (single) frequency band that falls somewhere within the larger frequency range of 2 to 10 Hz. This situation can occur if only one component dominates the plant seismic risk, or if a set of components having similar response frequencies dominate the risk; the frequency band of the dominant-risk components is narrow, but the actual location of this band is equally likely to be somewhere between 2 to 10 Hz. The important point here is that plant failure is sensitive to only a narrow response-frequency band in the range of 2 to 10 Hz, so that plant risk can be dominated by (i.e., significantly effected by) any value of the hazard measure within the range of 2 to 10 Hz.

Aside from this reasoning, there are other bases for selecting the 2 to 10 Hz average as a hazard measure of consideration. For instance, average spectral acceleration (over a frequency range) has been used recently to characterize ground motion potential for seismic PRAs (5,6), as this parameter is closely related to the damage effectiveness of earthquake motion (4). Furthermore, for probabilities of exceeding NUREG/CR-0098 or design-basis spectra, points defining exceedance-probability spectra exist at frequencies other than just 2.5 Hz, 5.0 Hz, and 10.0 Hz; taking an average insures that changes in slope of the spectra at these intermediate point are properly considered.

The average measure is simply obtained. In this study, values of spectral acceleration and exceedance probabilities are interpolated at each 0.5-Hz unit of frequency (this increment is sufficient to capture all points that define exceedance probability spectra). The interpolation of hazard measures assumes a linear variation in logarithm of the hazard measure with the logarithm of frequency. The average hazard measure is assessed as just the average of the 17 interpolated values between 2 to 10 Hz (inclusive).

As with the other hazard measures, the evaluation of averages occurs separately for mean, median, and 85th-fractile hazard statistics. For comparison purposes, the results are plots presenting (based on results for several sites) plant-to-plant values of peak exceedance probability or peak spectral acceleration, for a given hazard statistic.

4.4 RLE EVALUATION RELATIVE TO 0.3G FULL-SCOPE PLANTS

The process for determining whether or not an RLE evaluation of 0.3g full scope would be appropriate for a particular site that is initially assigned, by default, to the 0.5g bin, requires

plant-to-plant comparisons of mean, median, and 85th-fractile composite probabilities of exceeding the NUREG/CR–0098 spectrum (median, 5%-damped) anchored to a PGA value of 0.3g.

It is appropriate to first evaluate whether the median composite probability of exceeding the 0.3g spectrum is greater than 10^{-5} or whether the mean and 85th-fractile composite probabilities are greater than 10^{-4}. If either of these two conditions is not demonstrated, then their would not be a clearly supported basis for the 0.5g RLE assignment; on the other hand, if the test of the two conditions are both affirmative, then it is unlikely that a 0.3g RLE evaluation would be justifiable.

Given that the former case has been demonstrated, it would be appropriate to next make conditional RLE binning assignments for each of the three hazard statistics. For instance, if the composite hazard measure fell near or below the upper range of composite values comprising the set of 0.3g plants, then a conditional RLE binning assessment of 0.3g would be indicated; otherwise, a conditional RLE assignment of 0.5g would be required.

Consistent with the approach in NUREG–1407, conditional RLE binnings for all three hazard statistics would be required to clearly justify a 0.5g RLE assessment; if any one of the conditional binnings indicated a 0.3g RLE, then a final RLE evaluation of 0.3g would be supported.

The same approach as described here can be applied with other hazard measures (i.e., other than composite exceedance probabilities) as a means of confirming the robustness of RLE evaluation relative to binning of 0.3g plants.

4.5 RLE EVALUATION RELATIVE TO 0.3G FOCUSED-SCOPE PLANTS

Presuming that a supportable basis for a 0.3g RLE assessment can be made, it would be of interest and worthwhile to test if a plant meets criteria to implement focused-scope procedures. The process for determining whether or not such criteria are met requires plant-to-plant comparisons of mean, median, and 85th-fractile composite probabilities of exceeding seismic design-basis spectra. This process is consistent with the approach in NUREG–1407 for categorizing plants east of the Rocky Mountains into full-scope and focused-scope groups.

To categorize a 0.3g plant as full-scope or focused-scope, a conditional sub-grouping analysis similar to that described above (for conditional binning) could be conducted. For instance, if results for a particular composite (design-basis) hazard measure fell near or below the upper

range of composite values comprising the set of 0.3g focused-scope plants, then a conditional RLE categorization of focused-scope would be indicated.

If comparisons for all three hazard statistics were favorable for focused-scope assessment, there would be a clear basis for considering the implementation of focused-scope procedures (even if on a limited basis) as would be deemed appropriate in the expert judgment of the Seismic Review Team responsible for plant review.

4.6 RLE EVALUATION RELATIVE TO 0.5G PLANTS

Although not explicitly required by NUREG–1407, a default RLE evaluation of 0.5g can be refuted (and hence, further justification for a 0.3g RLE assignment can be achieved), by demonstrating dissimilarity in the hazard for PVNGS compared to the hazard for CEUS plants assigned to the 0.5g bin. Again, this is achieved by performing plant-to-plant comparisons of mean, median, and 85th-fractile composite probabilities of exceeding the NUREG/CR–0098 spectrum (median, 5%-damped) anchored to a PGA value of 0.3g.

By demonstrating exceedance probability results to be low with respect to the range of results for 0.5g CEUS plants, for the majority of hazard measures and hazard statistics, independent verification would be established to conclude that PVNGS does not belong in a default 0.5g RLE bin, but rather belongs in the 0.3g RLE bin.

The procedures described above for RLE evaluation and review-scope determination are implemented in the next section to develop relevant observations and recommendations for the Palo Verde Nuclear Generating Station.

4.7 REFERENCES

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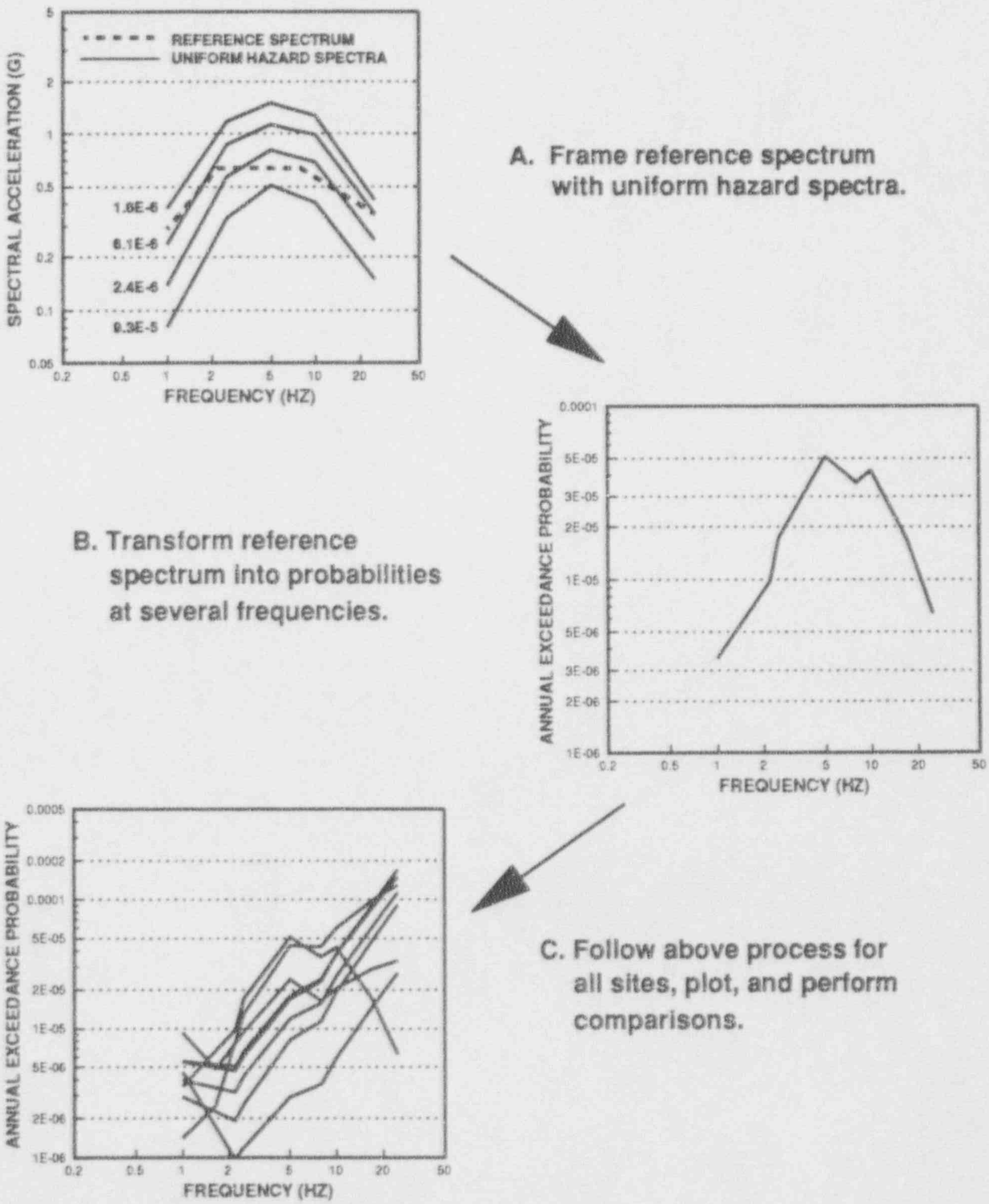
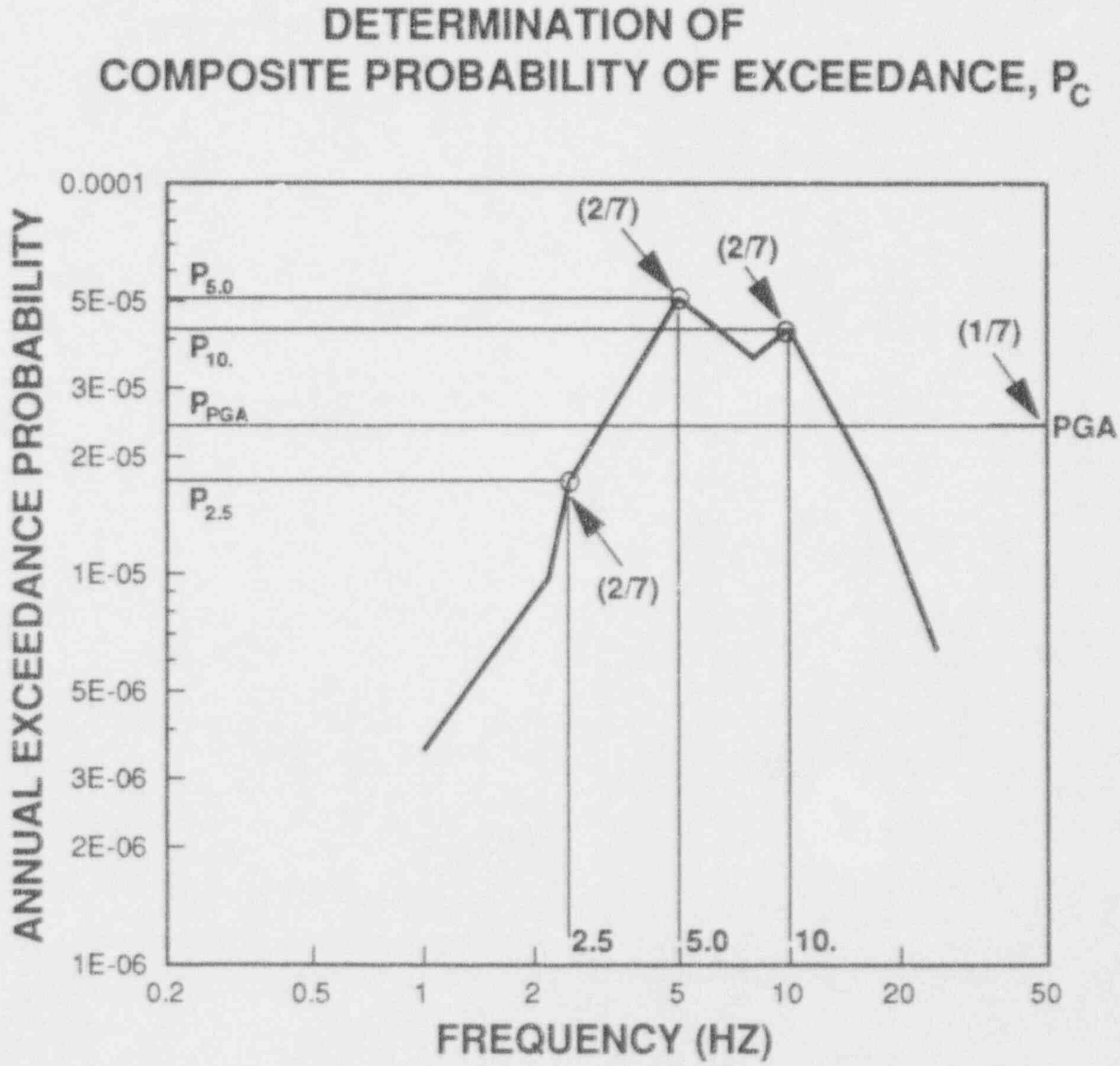


Figure 4-1. Illustration of process to convert a reference ground-motion spectrum to probabilities, through transformation of site-specific uniform seismic hazard spectra.



$$P_C = (2/7)(P_{2.5} + P_{5.0} + P_{10.}) + (1/7)(P_{PGA})$$

Figure 4-2. Illustration of weighting procedure to convert a spectrum of probabilities to a scalar, composite probability measure.

Section 5

COMPARISONS OF SEISMIC HAZARD MEASURES

This section implements the approaches described in Section 4 to obtain results of hazard-based measures, and to develop comparisons with central/eastern U.S. (CEUS) plants in the 0.3g full-scope and focused-scope bins. The hazard measures used or developed for comparison among 0.3g plants are of three primary forms: (1) probabilities of exceeding NUREG/CR-0098 spectra, (2) probabilities of exceeding seismic design spectra, and (3) uniform hazard spectra.

The detailed computational results of these hazard-based measures, including spectral results (with PGA results) and rankings of the various scalar hazard measures, are provided in Appendices A, B, and C. Brief discussions of these results are provided. In particular, composite hazard measures, based on the weighting criteria described in Section 4, are presented in this section; these *composite measures of exceedance probability are the primary basis for formulating or clarifying conclusions relevant to an appropriate RLE assessment for the PVNGS site.* General observations pertaining to the comparisons of the composite hazard measures are summarized. Observations are also made regarding comparisons for the other scalar hazard measures.

In addition to comparing hazard results among 0.3g CEUS plants, comparisons are also provided against hazard results for 0.5g (PRA) CEUS plant sites. The purpose of these additional comparisons, as discussed in Section 4, is to provide confirmation of the binning results established based on the 0.3g plants. In other words, if PVNGS is assigned to a 0.3g RLE bin based on similarity in hazard with other 0.3g plants, it is logical to expect that a 0.5g RLE assignment can be refuted based on dissimilarity in hazard with the 0.5g plants. To provide such confirmation, we again rely on scalar measures of probability of exceeding the NUREG/CR-0098 spectrum (median, 5%-damped) anchored to a PGA level of 0.3g. The detailed computational results and plant rankings for these hazard-based measures, are provided in Appendix D. Brief discussions of these results are provided in this section.

The implications of all the above comparisons, together with relevant conclusions and recommendations, are themselves provided in Section 6.

5.1 GENERAL DESCRIPTION OF COMPARISONS

5.1.1 Comparisons Among 0.3g CEUS Plants

Hazard measures are computed for 50 nuclear power plant sites in the central and eastern U.S., in addition to computations for the PVNGS site; hence, results for a total of 51 sites are considered as the basis for the hazard comparisons. The 50 CEUS sites comprise the set of 0.3g plants (full-scope or focused-scope) for which EPRI hazard results have been published (1). Table 5-1 lists the names of the 51 sites considered in the hazard comparisons. It is noted that there are 7 full-scope plants and 43 focused-scope plants among the set of 50 CEUS 0.3g sites.

Results in the appendices show plots of probability of exceedance spectra and uniform hazard spectra (51 curves on each graph), all of which indicate results for PGA. The results distinguish between full-scope plants, focused-scope plants, and the PVNGS site. The spectral comparisons allow one to determine general variations in hazard measures with respect to vibration frequency.

The composite probability results summarized in this section are presented as plots of weighted annual exceedance frequency versus re-ordered site number (51 points on each graph), where the ordering is performed so that results are presented from highest composite value to lowest. Similar plots have been produced for all scalar (frequency-independent) hazard measures introduced in Section 4.3. In all such ranking plots, it was considered unimportant to identify the specific plant associated with a particular result. Hence, a re-ordered site number does not pertain consistently (from hazard measure to hazard measure) to a specific plant, but rather, pertains to rankings of composite probabilities within the set of 0.3g plants (for a particular hazard measure). Rankings, on a plant-by-plant basis, which do indicate plant names, are provided in Tables 5-4 to 5-15.

5.1.2 Comparisons Among 0.5g CEUS Plants

The hazard measures computed for the 50 nuclear power plant sites in the 0.3g bin are combined with corresponding results computed for the two 0.5g (PRA) CEUS sites (Pilgrim and Seabrook); hence, results for a total of 53 sites have been considered as the basis for the hazard comparisons in Appendix D. Rankings for PVNGS results are provided separately, for each hazard measure and hazard statistic, among all 52 CEUS sites, among the 50 0.3g CEUS sites, and among the two 0.5g CEUS sites. Tables 5-4 to 5-15 provide plant-by-plant comparisons of the key results, indicating plant names.

5.2 COMPARISONS OF PROBABILITIES OF EXCEEDING 0.3G AND 0.5G NUREG/CR-0098 SPECTRA

Comparisons of probabilities of exceeding the 0.3g NUREG/CR-0098 spectrum are key factors in the RLE evaluation process. Spectral results (with PGA-based results) and scalar results are provided in Appendix A. Although not used in the RLE evaluation approach, probabilities of exceeding the NUREG/CR-0098 spectrum at a level of 0.5g are also presented to convey the impact of the ground-motion transformation basis (in particular, the motion severity level) on the conditional binning assessments.

5.2.1 Frequency-Dependent Probabilities

For PGA-based results (Figures A-1 to A-6), it is observed that probabilities of exceeding the 0.3g spectrum for the PVNGS site are well within the range of results defined by either the full-scope plants or the focused-scope plants, for all hazard statistics. Probabilities of exceeding the 0.5g NUREG/CR-0098 spectrum demonstrate an even somewhat more favorable comparison for the PVNGS site. For spectral values (Figures A-1 to A-6), comparisons of plots of probabilities of exceeding the 0.3g spectrum again reveal that mean and 85th-fractile values for the PVNGS site are generally within (for 5 Hz and greater), or close to (below 5 Hz), the bounds defined by the full-scope and focused-scope plants. The median results, however, lie notably above these bounds over the frequency range of 1 to 5 Hz (but notably below these bounds at 5 Hz and above). Probabilities of exceeding the 0.5g spectrum produce more-favorable comparisons; not only are the mean and 85th-fractile results substantially within the bounds of the 0.3g CEUS plants, but the PVNGS median results come closer (for frequencies below 5 Hz) to the bounds of the highest results defined by all other plants.

5.2.2 Composite Probabilities

The composite/weighted probabilities of exceeding the 0.3g NUREG/CR-0098 spectrum are shown in Figures A-7 to A-9. These plots reveal that the mean, median and 85th-fractile composite probabilities for the PVNGS site lie within the upper range of results for the 50 CEUS 0.3g sites; the relative comparison for the mean is somewhat more favorable than comparison for either the median or 85th-fractile. (The rankings for the PVNGS site based on these hazard measures are 4-of-51 based on the mean, 5-of-51 based on the median, and 4-of-51 based on the 85th-fractile).

Considering the RLE evaluation approach outlined in Section 4, these results produce 0.3g conditional binnings based on the mean, the median, and the 85th-fractile hazard measures;

a 0.5g conditional binning is not indicated for any h[illegible] measure. Hence, a final binning (unconditional on hazard measure) of 0.3g would be su[illegible] by these results.

As an additional verification that a 0.5g binning assignment is not supported for the PVNGS site, the mean and 85th-fractile composite probabilities are compared with a threshold of 10^{-4} and the median composite probability with a threshold of 10^{-5}. The binning approach in NUREG-1407 would require that the median composite probability exceed 10^{-5} and either the mean or 85th-fractile probability exceed 10^{-4} for a 0.5g binning assignment to be supported. Because, however, as indicated in Figures A-7 and A-9, both the mean and 85th-fractile composite-probability measures fall below the 10^{-4} threshold, and the median composite-probability measure (as indicated in Figure A-8) falls below the 10^{-5} level, a 0.5g binning assessment would not be supported for the PVNGS site.

These observations all indicate a 0.3g RLE binning assignment for the Palo Verde Nuclear Generating Station.

Figures A-10 to A-12 show mean, median, and 85th-fractile composite probabilities of exceeding the 0.5g NUREG/CR-0098 spectrum. The plots in these figures show that the PVNGS site again lies substantially within the upper range of probability results defined by the 0.3g CEUS sites, for all three hazard measures. The rankings for the mean, median, and 85th-fractile hazard measures are, respectively, 8-of-51, 8-of-51, and 5-of-51. In this case, the median hazard measure shows a more favorable relative comparison than previously. These results provide further support for the conclusion that the hazard at the PVNGS site is most similar to seismic hazards at plants in the 0.3g bin (as opposed to plants binned as 0.5g).

5.2.3 Other Scalar Probabilities

Ranking plots have been constructed for a variety of other scalar hazard measures derived from probabilities of exceeding NUREG/CR-0098 spectra; these are shown in Figures A-13 to A-30. The other scalar hazard measures consist of alternate-composite exceedance probability, peak exceedance probability over 2 to 10 Hz, and average exceedance probability over the same frequency range. Results for these cases are provided separately for each hazard statistic and for each anchor basis (0.3g and 0.5g) of the NUREG/CR-0098 spectrum. A summary of rankings for the PVNGS site produced from these comparisons is indicated in Table 5-2. In every case, the results in Table 5-2 support the conclusion that the hazard at the PVNGS site is most similar to that observed for plants in the 0.3g bin.

5.2.4 Comparisons Among 0.5g CEUS Plants

Scalar probabilities of exceeding the 0.3g NUREG/CR-0098 spectrum are also shown in Figures D-1 to D-12, which provide comparisons among results for the 0.5g plant sites. Ranking results are summarized in Table 5-3. The rankings for the PVNGS site among the 0.5g plants, in all cases, are 3-of-3, meaning that PVNGS has the lowest hazard among these plants. All cases presented in Table 5-3, therefore, support the conclusion that the hazard at the PVNGS site is dissimilar to (i.e., lower than) that observed for plants in the 0.5g bin.

5.3 COMPARISONS OF PROBABILITIES OF EXCEEDING PLANT-SPECIFIC SEISMIC DESIGN SPECTRA

Comparisons of probabilities of exceeding seismic design-basis spectra are important elements in deciding whether or not the application of focused-scope methods in IPEEE implementation is justified. For this aspect of the RLE evaluation of the PVNGS site, spectral results (with PGA-based results) and results for all scalar hazard measures are provided in Appendix B.

The seismic design-basis spectrum for the PVNGS site is the Reg. Guide 1.60 spectrum anchored to a peak ground acceleration of 0.25g, whereas the SSE level for licensing purposes (based on seismological studies described in the safety analysis report) is 0.2g (2). Because the actual design basis acceleration, as opposed to the lower (minimum required) SSE acceleration, impacts component capacities, the 0.25g spectrum is the appropriate one for transforming hazard results to probabilities of exceeding seismic design. The seismic design bases for the 50 CEUS 0.3g plants were derived from data provided by LLNL; it is believed that these data are the same as those used in the NUREG-1407 studies.

5.3.1 Frequency-Dependent Probabilities

For PGA-based results (Figures B-1 to B-3), it is observed that probabilities of exceeding the design spectrum for the PVNGS site are well within the lower range of results defined by the focused-scope plants, for all hazard statistics. For spectral results (Figures B-1 to B-3) also, comparisons of plots of probabilities of exceeding design-basis spectra reveal that all values for the PVNGS site are well within the bounds defined by the focused-scope plants.

5.3.2 Composite Probabilities

The composite/weighted probabilities of exceeding seismic design-basis spectra are shown in Figures B-4 to B-6. These plots reveal that the mean composite probabilities for the PVNGS site lie clearly within the lower range of probability results for the 43 CEUS 0.3g focused-scope plants. The rankings for the PVNGS site (based on these composite probabilities) are

34-of-44, 35-of-44, and 32-of-44 among focused-scope plants, based respectively on the mean, median and 85th-fractile hazards.

Considering the RLE evaluation approach outlined in Section 4, these results would indicate a focused-scope conditional sub-grouping based on each of the three hazard statistics. Because all three hazard measures here indicate a focused-scope sub-grouping, a focused-scope categorization is clearly supported for the PVNGS site. Although NUREG–1407 does not allow for the use of focused-scope procedures on an exclusive basis at the PVNGS site, it would be reasonable to consider the appropriate use of specific focused-scope techniques that may be found to apply depending upon the lessons learned from full-scope investigation of one of the three reactor units at the PVNGS site.

These considerations favor the application of focused-scope techniques, on an as-appropriate basis, for seismic-IPEEE review of the Palo Verde Nuclear Generating Station.

5.3.3 Other Scalar Probabilities

Ranking plots have been constructed for a variety of other scalar hazard measures derived from probabilities of exceeding design-basis spectra; these are shown in Figures B–7 to B–15. The other s ar hazard measures consist of alternate-composite exceedance probability, peak exceedance probability over 2 to 10 Hz, and average exceedance probability over the same frequency range. Results for these cases are provided separately for each hazard statistic. A summary of rankings for the PVNGS site produced from these comparisons is indicated in the second part of Table 5–2. In every case, the results in Table 5–2 support the basis for drawing the preceding conclusions regarding the application of focused-scope techniques at PVNGS.

5.4 COMPARISONS OF UNIFORM HAZARD SPECTRA

5.4.1 Frequency-Dependent Results

Uniform hazard spectra themselves are not used as a binning basis in the RLE evaluation approach. But nonetheless, comparisons of UHS are useful in checking with subsequent results. Appendix C presents spectral and PGA-based comparisons of ground-motion ordinates at uniform hazard levels of 10^{-3}, 10^{-4}, and 10^{-5}. For each uniform hazard level, results are provided for mean, median, and 85th-fractile hazard statistics; hence, a total of 9 plots of spectral results (that also include PGA results) may be considered.

For the PGA results (Figures C–1 to C–9), it may be observed that the values for PVNGS fall clearly within the hazard limits defined by the full-scope plants or the focused-scope

plants for all uniform-hazard levels and for all hazard statistics. For the other spectral results (Figures C-1 to C-9), it is observed that the plots for the PVNGS site fall significantly within (or very nearly within) the range of curves defined by the 0.3g plants for the mean and 85th-fractile hazard statistics (regardless of the uniform-hazard level). Generally speaking (for vibration frequencies of interest), the PVNGS results are highest, comparatively, over the frequency range of 2.5 to 5 Hz; this observation is associated with the expected difference in spectral-shape characteristics between the PVNGS site and the CEUS sites. Whereas the PVNGS spectra peak at 5 Hz, they become very low (comparatively) at a frequency of 25 Hz. The severest comparisons for the PVNGS site are seen in the median UHS results, where ordinates lie somewhat above the limits for CEUS site over the frequency range of 1 to 5 Hz.

As a consequence of these observations, one may generally expect that subsequent comparisons of the mean and 85th-fractile results will be substantially within the limits defined by the CEUS 0.3g sites, whereas the median comparisons (for spectra) may be somewhat less favorable in the 1-Hz to 5-Hz range.

5.4.2 Scalar Results

Also not explicitly part of the RLE binning evaluation (but nonetheless useful for verification purposes) are ranking plots for scalar hazard measures derived from uniform hazard spectra; these are shown in Figures C-10 to C-27. The hazard measures consist of both peak spectral acceleration (S_a) over 2 to 10 Hz and average spectral acceleration over the same frequency range; results for these cases are provided separately for each hazard statistic and each annual exceedance probability (uniform hazard) level. A summary of rankings for the PVNGS site produced from these comparisons is indicated in the last part of Table 5-2. From these comparisons, it is seen that all scalar hazard results for PVNGS fall within the range of results for the 0.3g CEUS plants, except for two isolated cases (out of 18 total comparisons). In each of these cases, however, Figures C-20 and C-26 indicate that the absolute value of the hazard measure is very nearly the same as the value defining the upper-bound range for the 0.3g CEUS plants.

The observations summarized in this section, concerning comparisons of composite probabilities of exceeding the 0.3g NUREG/CR-0098 spectrum, composite probabilities of exceeding design spectra, and supporting comparisons for other hazard measures, form the basis for conclusions and recommendations discussed in Section 6.

5.5 REFERENCES

1. R. K. McGuire, G. R. Toro, J. P. Jacobson, T. F. O'Hara, and W. J. Silva. *Probabilistic Seismic Hazard Evaluations at Nuclear Plant Sites in the Central and Eastern United States: Resolution of the Charleston Earthquake Issue.* Technical Report NP-6395-D, Main Report, Electric Power Research Institute, April 1989.

2. Arizona Public Service. *Palo Verde Nuclear Generating Station: Final Safety Analysis Report.* Volume 3, Updated March 1991.

Table 5-1

LIST OF PLANTS USED IN HAZARD COMPARISONS

Plant Name	Review Type
— 0.3g Sites —	
Arkansas	Full Scope
Beaver Valley	Focused Scope
Bellefonte	Focused Scope
Braidwood	Focused Scope
Browns Ferry	Focused Scope
Brunswick	Focused Scope
Byron	Focused Scope
Calvert Cliffs	Focused Scope
Catawba	Focused Scope
Clinton	Focused Scope
Davis Besse	Focused Scope
Dresden	Focused Scope
Farley	Focused Scope
Fermi	Focused Scope
Fitzpatrick	Focused Scope
Ginna	Focused Scope
Haddam Neck	Focused Scope
Hatch	Focused Scope
Hope Creek	Focused Scope
Indian Point	Full Scope
Kewaunee	Focused Scope
La Salle	Focused Scope
Limerick	Focused Scope
Maine Yankee	Full Scope
McGuire	Focused Scope
Millstone	Focused Scope
Monticello	Focused Scope
Nine Mile Point	Focused Scope
North Anna	Focused Scope
Oconee	Full Scope
Oyster Creek	Focused Scope
Palo Verde	—
Peach Bottom	Focused Scope
Perry	Focused Scope
Point Beach	Focused Scope
Prairie Island	Focused Scope
Quad Cities	Focused Scope
Robinson	Full Scope
Salem	Focused Scope
Sequoyah	Full Scope
Shearon Harris	Focused Scope
Summer	Focused Scope
Surry	Focused Scope
Susquehanna	Focused Scope
Three Mile Island	Focused Scope
Vermont Yankee	Focused Scope
Vogtle	Focused Scope
Watts Bar	Focused Scope
Wolf Creek	Focused Scope
Yankee Rowe	Full Scope
Zion	Focused Scope
— 0.5g Sites —	
Pilgrim	0.5g / PRA
Seabrook	0.5g / PRA

Table 5-2

SUMMARY OF RANKINGS FOR PVNGS HAZARD MEASURES AMONG RESULTS FOR 0.3g PLANTS

		Rankings (Out of 51 Total Plants) and Figure References for Hazard-Measure Statistic:		
Hazard Measure	Comparison	Mean	Median	85th Fractile
Probability of Exceeding 0.3g NUREG/CR-0098 Spectrum	Composite	4 (Fig. A-7)	5 (Fig. A-8)	4 (Fig. A-9)
	Alternate Composite	2 (Fig. A-13)	2 (Fig. A-14)	2 (Fig. A-15)
	Peak (2 to 10 Hz)	4 (Fig. A-19)	5 (Fig. A-20)	5 (Fig. A-21)
	Average (2 to 10 Hz)	2 (Fig. A-25)	2 (Fig. A-26)	2 (Fig. A-27)
Probability of Exceeding 0.5g NUREG/CR-0098 Spectrum	Composite	8 (Fig. A-10)	8 (Fig. A-11)	5 (Fig. A-12)
	Alt. Composite	4 (Fig. A-16)	4 (Fig. A-17)	3 (Fig. A-18)
	Peak (2 to 10 Hz)	6 (Fig. A-22)	12 (Fig. A-23)	5 (Fig. A-24)
	Average (2 to 10 Hz)	5 (Fig. A-28)	3 (Fig. A-29)	3 (Fig. A-30)
Probability of Exceeding the Design-Basis Spectrum	Composite	41 (Fig. B-4)	42 (Fig. B-5)	39 (Fig. B-6)
	Alt. Composite	39 (Fig. B-7)	40 (Fig. B-8)	39 (Fig. B-9)
	Peak (2 to 10 Hz)	43 (Fig. B-10)	45 (Fig. B-11)	42 (Fig. B-12)
	Average (2 to 10 Hz)	39 (Fig. B-13)	38 (Fig. B-14)	39 (Fig. B-15)
10^{-3} S_a	Peak (2 to 10 Hz)	6 (Fig. C-10)	5 (Fig. C-11)	10 (Fig. C-12)
	Average (2 to 10 Hz)	3 (Fig. C-19)	2 (Fig. C-20)	5 (Fig. C-21)
10^{-4} S_a	Peak (2 to 10 Hz)	2 (Fig. C-13)	4 (Fig. C-14)	2 (Fig. C-15)
	Average (2 to 10 Hz)	4 (Fig. C-22)	1 (Fig. C-23)	3 (Fig. C-24)
10^{-5} S_a	Peak (2 to 10 Hz)	2 (Fig. C-16)	3 (Fig. C-17)	3 (Fig. C-18)
	Average (2 to 10 Hz)	2 (Fig. C-25)	1 (Fig. C-26)	2 (Fig. C-27)

Table 5-3

SUMMARY OF RANKINGS FOR PVNGS HAZARD MEASURES AMONG RESULTS FOR 0.5g PLANTS

		Rankings (Out of 3 Total Plants) and Figure References for Hazard-Measure Statistic:		
Hazard Measure	Comparison	Mean	Median	85th Fractile
Probability of	Composite	3 (Fig. D-1)	3 (Fig. D-2)	3 (Fig. D-3)
Exceeding 0.3g	Alternate Composite	3 (Fig. D-4)	3 (Fig. D-5)	3 (Fig. D-6)
NUREG/CR-0098	Peak (2 to 10 Hz)	3 (Fig. D-7)	3 (Fig. D-8)	3 (Fig. D-9)
Spectrum	Average (2 to 10 Hz)	3 (Fig. D-10)	3 (Fig. D-11)	3 (Fig. D-12)

Table 5-4

RANKINGS, INDICATING PLANT NAMES, OF MEAN COMPOSITE PROBABILITY OF EXCEEDING NUREG/CR-0098 SPECTRUM ANCHORED TO 0.3G; 50 0.3G SITES, TWO 0.5G SITES, AND THE PVNGS SITE

Plant Name	Review Type	Hazard	Plant Name	Review Type	Hazard
PILGRIM	0.5g (PRA)	1.01E-04	MONTICELLO	0.3g Focused	9.39E-06
YANKEE ROWE	0.3g Full	4.33E-05	POINT BEACH	0.3g Focused	9.37E-06
SEABROOK	0.5g (PRA)	3.41E-05	CALVERT CLIFFS	0.3g Focused	8.40E-06
INDIAN POINT	0.3g Full	2.55E-05	BEAVER VALLEY	0.3g Focused	8.36E-06
SEQUOYAH	0.3g Full	2.54E-05	MCGUIRE	0.3g Focused	7.99E-06
PALO VERDE	—	2.41E-05	BELLEFONTE	0.3g Focused	7.84E-06
HADDAM NECK	0.3g Focused	2.18E-05	THREE MILE ISLAND	0.3g Focused	7.44E-06
WATTS BAR	0.3g Focused	2.18E-05	HATCH	0.3g Focused	5.76E-06
CLINTON	0.3g Focused	2.12E-05	FERMI	0.3g Focused	5.62E-06
NORTH ANNA	0.3g Focused	2.11E-05	VERMONT YANKEE	0.3g Focused	5.23E-06
VOGTLE	0.3g Focused	2.08E-05	GINNA	0.3g Focused	4.85E-06
BRUNSWICK	0.3g Focused	2.02E-05	ARKANSAS	0.3g Full	4.06E-06
LA SALLE	0.3g Focused	1.96E-05	BROWNS FERRY	0.3g Focused	3.88E-06
SALEM	0.3g Focused	1.96E-05	DAVIS BESSE	0.3g Focused	3.87E-06
HOPE CREEK	0.3g Focused	1.96E-05	PRAIRIE ISLAND	0.3g Focused	3.66E-06
ROBINSON	0.3g Full	1.77E-05	SUSQUEHANNA	0.3g Focused	3.14E-06
OCONEE	0.3g Full	1.72E-05	PERRY	0.3g Focused	2.99E-06
OYSTER CREEK	0.3g Focused	1.68E-05	BYRON	0.3g Focused	2.58E-06
ZION	0.3g Focused	1.67E-05	SHEARON HARRIS	0.3g Focused	2.37E-06
MILLSTONE	0.3g Focused	1.42E-05	DRESDEN	0.3g Focused	2.33E-06
SURRY	0.3g Focused	1.42E-05	BRAIDWOOD	0.3g Focused	2.05E-06
CATAWBA	0.3g Focused	1.32E-05	WOLF CREEK	0.3g Focused	1.94E-06
MAINE YANKEE	0.3g Full	1.26E-05	QUAD CITIES	0.3g Focused	1.73E-06
LIMERICK	0.3g Focused	1.22E-05	FITZPATRICK	0.3g Focused	1.66E-06
SUMMER	0.3g Focused	1.12E-05	NINE MILE POINT	0.3g Focused	1.66E-06
KEWAUNEE	0.3g Focused	9.73E-06	FARLEY	0.3g Focused	6.95E-07
PEACH BOTTOM	0.3g Focused	9.42E-06			

Table 5-5

RANKINGS, INDICATING PLANT NAMES, OF MEDIAN COMPOSITE PROBABILITY OF EXCEEDING NUREG/CR-0098 SPECTRUM ANCHORED TO 0.3G; 50 0.3G SITES, TWO 0.5G SITES, AND THE PVNGS SITE

Plant Name	Review Type	Hazard	Plant Name	Review Type	Hazard
PILGRIM	0.5g (PRA)	3.42E-05	BELLEFONTE	0.3g Focused	2.62E-06
SEABROOK	0.5g (PRA)	1.75E-05	MONTICELLO	0.3g Focused	2.41E-06
SEQUOYAH	0.3g Full	1.21E-05	PEACH BOTTOM	0.3g Focused	2.28E-06
YANKEE ROWE	0.3g Full	1.21E-05	OYSTER CREEK	0.3g Focused	2.18E-06
NORTH ANNA	0.3g Focused	9.60E-06	VERMONT YANKEE	0.3g Focused	2.05E-06
WATTS BAR	0.3g Focused	9.45E-06	BEAVER VALLEY	0.3g Focused	1.95E-06
PALO VERDE	—	9.35E-06	DAVIS BESSE	0.3g Focused	1.50E-06
INDIAN POINT	0.3g Full	7.73E-06	ARKANSAS	0.3g Full	1.49E-06
HADDAM NECK	0.3g Focused	7.19E-06	GINNA	0.3g Focused	1.41E-06
MAINE YANKEE	0.3g Full	7.00E-06	FERMI	0.3g Focused	1.37E-06
OCONEE	0.3g Full	6.82E-06	SURRY	0.3g Focused	1.24E-06
LA SALLE	0.3g Focused	5.59E-06	BROWNS FERRY	0.3g Focused	1.04E-06
MILLSTONE	0.3g Focused	5.29E-06	SUSQUEHANNA	0.3g Focused	9.98E-07
CATAWBA	0.3g Focused	5.22E-06	BYRON	0.3g Focused	9.19E-07
LIMERICK	0.3g Focused	5.05E-06	PERRY	0.3g Focused	8.74E-07
ZION	0.3g Focused	4.93E-06	WOLF CREEK	0.3g Focused	8.50E-07
SUMMER	0.3g Focused	4.58E-06	CALVERT CLIFFS	0.3g Focused	8.18E-07
BRUNSWICK	0.3g Focused	4.56E-06	DRESDEN	0.3g Focused	7.78E-07
VOGTLE	0.3g Focused	3.67E-06	BRAIDWOOD	0.3g Focused	7.34E-07
SALEM	0.3g Focused	3.43E-06	PRAIRIE ISLAND	0.3g Focused	6.75E-07
HOPE CREEK	0.3g Focused	3.43E-06	FITZPATRICK	0.3g Focused	6.44E-07
MCGUIRE	0.3g Focused	3.34E-06	NINE MILE POINT	0.3g Focused	6.44E-07
ROBINSON	0.3g Full	3.27E-06	HATCH	0.3g Focused	6.03E-07
CLINTON	0.3g Focused	3.00E-06	SHEARON HARRIS	0.3g Focused	5.51E-07
THREE MILE ISLAND	0.3g Focused	2.96E-06	QUAD CITIES	0.3g Focused	4.19E-07
KEWAUNEE	0.3g Focused	2.95E-06	FARLEY	0.3g Focused	1.21E-07
POINT BEACH	0.3g Focused	2.63E-06			

Table 5-6

RANKINGS, INDICATING PLANT NAMES, OF 85TH-FRACTILE COMPOSITE PROBABILITY OF EXCEEDING NUREG/CR-0098 SPECTRUM ANCHORED TO 0.3G; 50 0.3G SITES, TWO 0.5G SITES, AND THE PVNGS SITE

Plant Name	Review Type	Hazard	Plant Name	Review Type	Hazard
PILGRIM	0.5g (PRA)	1.72E-04	KEWAUNEE	0.3g Focused	1.50E-05
YANKEE ROWE	0.3g Full	7.09E-05	POINT BEACH	0.3g Focused	1.42E-05
SEABROOK	0.5g (PRA)	6.68E-05	MONTICELLO	0.3g Focused	1.39E-05
INDIAN POINT	0.3g Full	4.86E-05	THREE MILE ISLAND	0.3g Focused	1.33E-05
SEQUOYAH	0.3g Full	4.74E-05	BELLEFONTE	0.3g Focused	1.23E-05
PALO VERDE	—	4.49E-05	BEAVER VALLEY	0.3g Focused	1.18E-05
WATTS BAR	0.3g Focused	4.30E-05	CALVERT CLIFFS	0.3g Focused	9.41E-06
NORTH ANNA	0.3g Focused	3.82E-05	VERMONT YANKEE	0.3g Focused	9.08E-06
HADDAM NECK	0.3g Focused	3.14E-05	GINNA	0.3g Focused	7.58E-06
VOGTLE	0.3g Focused	3.10E-05	FERMI	0.3g Focused	6.71E-06
ROBINSON	0.3g Full	3.10E-05	HATCH	0.3g Focused	6.34E-06
LA SALLE	0.3g Focused	2.90E-05	DAVIS BESSE	0.3g Focused	6.28E-06
BRUNSWICK	0.3g Focused	2.78E-05	ARKANSAS	0.3g Full	5.89E-06
OCONEE	0.3g Full	2.76E-05	BROWNS FERRY	0.3g Focused	5.21E-06
CATAWBA	0.3g Focused	2.66E-05	SUSQUEHANNA	0.3g Focused	5.12E-06
CLINTON	0.3g Focused	2.66E-05	PERRY	0.3g Focused	4.71E-06
MAINE YANKEE	0.3g Full	2.52E-05	PRAIRIE ISLAND	0.3g Focused	4.12E-06
SALEM	0.3g Focused	2.27E-05	SHEARON HARRIS	0.3g Focused	3.82E-06
HOPE CREEK	0.3g Focused	2.27E-05	BYRON	0.3g Focused	3.72E-06
ZION	0.3g Focused	2.26E-05	DRESDEN	0.3g Focused	3.56E-06
MILLSTONE	0.3g Focused	2.11E-05	BRAIDWOOD	0.3g Focused	3.42E-06
SUMMER	0.3g Focused	2.08E-05	WOLF CREEK	0.3g Focused	3.39E-06
OYSTER CREEK	0.3g Focused	1.93E-05	NINE MILE POINT	0.3g Focused	3.15E-06
LIMERICK	0.3g Focused	1.92E-05	FITZPATRICK	0.3g Focused	3.15E-06
PEACH BOTTOM	0.3g Focused	1.63E-05	QUAD CITIES	0.3g Focused	2.56E-06
MCGUIRE	0.3g Focused	1.61E-05	FARLEY	0.3g Focused	8.06E-07
SURRY	0.3g Focused	1.52E-05			

Table 5-7

RANKINGS, INDICATING PLANT NAMES, OF MEAN ALTERNATE-COMPOSITE PROBABILITY OF EXCEEDING NUREG/CR-0098 SPECTRUM ANCHORED TO 0.3G; 50 0.3G SITES, TWO 0.5G SITES, AND THE PVNGS SITE

Plant Name	Review Type	Hazard	Plant Name	Review Type	Hazard
PILGRIM	0.5g (PRA)	8.76E-05	MONTICELLO	0.3g Focused	7.68E-06
YANKEE ROWE	0.3g Full	3.87E-05	PEACH BOTTOM	0.3g Focused	7.63E-06
SEABROOK	0.5g (PRA)	2.72E-05	POINT BEACH	0.3g Focused	7.47E-06
PALO VERDE	—	2.32E-05	BEAVER VALLEY	0.3g Focused	7.12E-06
VOGTLE	0.3g Focused	2.11E-05	MCGUIRE	0.3g Focused	6.50E-06
INDIAN POINT	0.3g Full	2.08E-05	BELLEFONTE	0.3g Focused	6.10E-06
SEQUOYAH	0.3g Full	2.03E-05	THREE MILE ISLAND	0.3g Focused	5.97E-06
HOPE CREEK	0.3g Focused	1.93E-05	HATCH	0.3g Focused	5.78E-06
SALEM	0.3g Focused	1.93E-05	FERMI	0.3g Focused	4.48E-06
CLINTON	0.3g Focused	1.90E-05	VERMONT YANKEE	0.3g Focused	4.16E-06
BRUNSWICK	0.3g Focused	1.84E-05	GINNA	0.3g Focused	3.89E-06
ROBINSON	0.3g Full	1.80E-05	ARKANSAS	0.3g Full	3.33E-06
HADDAM NECK	0.3g Focused	1.75E-05	DAVIS BESSE	0.3g Focused	3.04E-06
WATTS BAR	0.3g Focused	1.75E-05	BROWNS FERRY	0.3g Focused	3.02E-06
NORTH ANNA	0.3g Focused	1.74E-05	PRAIRIE ISLAND	0.3g Focused	2.93E-06
OYSTER CREEK	0.3g Focused	1.68E-05	SUSQUEHANNA	0.3g Focused	2.52E-06
LA SALLE	0.3g Focused	1.65E-05	PERRY	0.3g Focused	2.26E-06
SURRY	0.3g Focused	1.45E-05	BYRON	0.3g Focused	1.96E-06
ZION	0.3g Focused	1.40E-05	SHEARON HARRIS	0.3g Focused	1.87E-06
OCONEE	0.3g Full	1.39E-05	DRESDEN	0.3g Focused	1.76E-06
MILLSTONE	0.3g Focused	1.15E-05	BRAIDWOOD	0.3g Focused	1.55E-06
CATAWBA	0.3g Focused	1.07E-05	WOLF CREEK	0.3g Focused	1.50E-06
MAINE YANKEE	0.3g Full	9.95E-06	QUAD CITIES	0.3g Focused	1.33E-06
LIMERICK	0.3g Focused	9.93E-06	FITZPATRICK	0.3g Focused	1.27E-06
SUMMER	0.3g Focused	9.20E-06	NINE MILE POINT	0.3g Focused	1.27E-06
CALVERT CLIFFS	0.3g Focused	8.54E-06	FARLEY	0.3g Focused	5.60E-07
KEWAUNEE	0.3g Focused	8.20E-06			

Table 5-8

RANKINGS, INDICATING PLANT NAMES, OF MEDIAN ALTERNATE-COMPOSITE PROBABILITY OF EXCEEDING NUREG/CR-0098 SPECTRUM ANCHORED TO 0.3G; 50 0.3G SITES, TWO 0.5G SITES, AND THE PVNGS SITE

Plant Name	Review Type	Hazard	Plant Name	Review Type	Hazard
PILGRIM	0.5g (PRA)	2.68E-05	OYSTER CREEK	0.3g Focused	1.76E-06
SEABROOK	0.5g (PRA)	1.06E-05	MONTICELLO	0.3g Focused	1.75E-06
YANKEE ROWE	0.3g Full	9.53E-06	BELLEFONTE	0.3g Focused	1.48E-06
PALO VERDE	—	8.31E-06	BEAVER VALLEY	0.3g Focused	1.42E-06
SEQUOYAH	0.3g Full	7.49E-06	PEACH BOTTOM	0.3g Focused	1.36E-06
NORTH ANNA	0.3g Focused	6.45E-06	VERMONT YANKEE	0.3g Focused	1.24E-06
WATTS BAR	0.3g Focused	5.99E-06	SURRY	0.3g Focused	1.01E-06
INDIAN POINT	0.3g Full	4.71E-06	ARKANSAS	0.3g Full	9.20E-07
LA SALLE	0.3g Focused	4.38E-06	GINNA	0.3g Focused	8.82E-07
HADDAM NECK	0.3g Focused	4.37E-06	DAVIS BESSE	0.3g Focused	8.64E-07
MAINE YANKEE	0.3g Full	4.18E-06	FERMI	0.3g Focused	8.20E-07
OCONEE	0.3g Full	4.14E-06	CALVERT CLIFFS	0.3g Focused	6.36E-07
ZION	0.3g Focused	3.72E-06	BROWNS FERRY	0.3g Focused	6.18E-07
BRUNSWICK	0.3g Focused	3.70E-06	SUSQUEHANNA	0.3g Focused	5.91E-07
CATAWBA	0.3g Focused	3.24E-06	BYRON	0.3g Focused	5.19E-07
MILLSTONE	0.3g Focused	3.13E-06	WOLF CREEK	0.3g Focused	5.06E-07
LIMERICK	0.3g Focused	3.09E-06	HATCH	0.3g Focused	4.82E-07
VOGTLE	0.3g Focused	3.02E-06	PRAIRIE ISLAND	0.3g Focused	4.68E-07
SUMMER	0.3g Focused	2.95E-06	PERRY	0.3g Focused	4.40E-07
HOPE CREEK	0.3g Focused	2.70E-06	DRESDEN	0.3g Focused	4.30E-07
SALEM	0.3g Focused	2.70E-06	BRAIDWOOD	0.3g Focused	4.18E-07
ROBINSON	0.3g Full	2.64E-06	FITZPATRICK	0.3g Focused	3.88E-07
CLINTON	0.3g Focused	2.24E-06	NINE MILE POINT	0.3g Focused	3.88E-07
KEWAUNEE	0.3g Focused	2.22E-06	SHEARON HARRIS	0.3g Focused	3.16E-07
MCGUIRE	0.3g Focused	1.96E-06	QUAD CITIES	0.3g Focused	2.02E-07
THREE MILE ISLAND	0.3g Focused	1.92E-06	FARLEY	0.3g Focused	5.48E-08
POINT BEACH	0.3g Focused	1.77E-06			

Table 5-9

RANKINGS, INDICATING PLANT NAMES, OF 85TH-FRACTILE ALTERNATE COMPOSITE PROBABILITY OF EXCEEDING NUREG/CR-0098 SPECTRUM ANCHORED TO 0.3G; 50 0.3G SITES, TWO 0.5G SITES, AND THE PVNGS SITE

Plant Name	Review Type	Hazard	Plant Name	Review Type	Hazard
PILGRIM	0.5g (PRA)	1.51E-04	KEWAUNEE	0.3g Focused	1.21E-05
YANKEE ROWE	0.3g Full	6.32E-05	MONTICELLO	0.3g Focused	1.12E-05
SEABROOK	0.5g (PRA)	5.78E-05	POINT BEACH	0.3g Focused	1.06E-05
PALO VERDE	—	4.38E-05	BEAVER VALLEY	0.3g Focused	9.68E-06
INDIAN POINT	0.3g Full	4.09E-05	THREE MILE ISLAND	0.3g Focused	9.42E-06
SEQUOYAH	0.3g Full	3.58E-05	CALVERT CLIFFS	0.3g Focused	8.91E-06
WATTS BAR	0.3g Focused	3.36E-05	BELLEFONTE	0.3g Focused	8.51E-06
ROBINSON	0.3g Full	3.12E-05	VERMONT YANKEE	0.3g Focused	6.87E-06
NORTH ANNA	0.3g Focused	3.11E-05	HATCH	0.3g Focused	6.03E-06
VOGTLE	0.3g Focused	3.10E-05	GINNA	0.3g Focused	5.63E-06
BRUNSWICK	0.3g Focused	2.45E-05	FERMI	0.3g Focused	5.17E-06
LA SALLE	0.3g Focused	2.36E-05	DAVIS BESSE	0.3g Focused	4.76E-06
CLINTON	0.3g Focused	2.36E-05	ARKANSAS	0.3g Full	4.17E-06
CATAWBA	0.3g Focused	2.24E-05	BROWNS FERRY	0.3g Focused	3.84E-06
MAINE YANKEE	0.3g Full	2.17E-05	SUSQUEHANNA	0.3g Focused	3.71E-06
OCONEE	0.3g Full	2.10E-05	PERRY	0.3g Focused	3.21E-06
HADDAM NECK	0.3g Focused	2.07E-05	PRAIRIE ISLAND	0.3g Focused	3.11E-06
HOPE CREEK	0.3g Focused	2.01E-05	SHEARON HARRIS	0.3g Focused	2.75E-06
SALEM	0.3g Focused	2.01E-05	BYRON	0.3g Focused	2.54E-06
ZION	0.3g Focused	1.79E-05	DRESDEN	0.3g Focused	2.46E-06
OYSTER CREEK	0.3g Focused	1.75E-05	WOLF CREEK	0.3g Focused	2.46E-06
SUMMER	0.3g Focused	1.71E-05	BRAIDWOOD	0.3g Focused	2.35E-06
LIMERICK	0.3g Focused	1.49E-05	FITZPATRICK	0.3g Focused	2.20E-06
SURRY	0.3g Focused	1.48E-05	NINE MILE POINT	0.3g Focused	2.20E-06
MILLSTONE	0.3g Focused	1.47E-05	QUAD CITIES	0.3g Focused	1.53E-06
MCGUIRE	0.3g Focused	1.37E-05	FARLEY	0.3g Focused	6.28E-07
PEACH BOTTOM	0.3g Focused	1.21E-05			

Table 5-10

RANKINGS, INDICATING PLANT NAMES, OF PEAK (2 TO 10 HZ) MEAN PROBABILITY OF EXCEEDING NUREG/CR-0098 SPECTRUM ANCHORED TO 0.3G; 50 0.3G SITES, TWO 0.5G SITES, AND THE PVNGS SITE

Plant Name	Review Type	Hazard	Plant Name	Review Type	Hazard
PILGRIM	0.5g (PRA)	1.49E-04	MONTICELLO	0.3g Focused	1.56E-05
YANKEE ROWE	0.3g Full	5.95E-05	PEACH BOTTOM	0.3g Focused	1.40E-05
SEABROOK	0.5g (PRA)	5.11E-05	BEAVER VALLEY	0.3g Focused	1.27E-05
SEQUOYAH	0.3g Full	3.79E-05	BELLEFONTE	0.3g Focused	1.20E-05
INDIAN POINT	0.3g Full	3.76E-05	CALVERT CLIFFS	0.3g Focused	1.19E-05
PALO VERDE	—	3.26E-05	MCGUIRE	0.3g Focused	1.18E-05
WATTS BAR	0.3g Focused	3.23E-05	THREE MILE ISLAND	0.3g Focused	1.11E-05
HADDAM NECK	0.3g Focused	3.21E-05	FERMI	0.3g Focused	8.44E-06
NORTH ANNA	0.3g Focused	3.07E-05	VERMONT YANKEE	0.3g Focused	7.78E-06
LA SALLE	0.3g Focused	2.99E-05	HATCH	0.3g Focused	7.55E-06
VOGTLE	0.3g Focused	2.83E-05	GINNA	0.3g Focused	7.23E-06
CLINTON	0.3g Focused	2.70E-05	PRAIRIE ISLAND	0.3g Focused	6.19E-06
BRUNSWICK	0.3g Focused	2.65E-05	BROWNS FERRY	0.3g Focused	6.02E-06
SALEM	0.3g Focused	2.61E-05	ARKANSAS	0.3g Full	5.87E-06
HOPE CREEK	0.3g Focused	2.61E-05	DAVIS BESSE	0.3g Focused	5.78E-06
ZION	0.3g Focused	2.55E-05	SUSQUEHANNA	0.3g Focused	4.70E-06
OCONEE	0.3g Full	2.54E-05	PERRY	0.3g Focused	4.64E-06
ROBINSON	0.3g Full	2.41E-05	BYRON	0.3g Focused	3.98E-06
OYSTER CREEK	0.3g Focused	2.20E-05	SHEARON HARRIS	0.3g Focused	3.61E-06
KEWAUNEE	0.3g Focused	2.20E-05	DRESDEN	0.3g Focused	3.60E-06
MILLSTONE	0.3g Focused	2.10E-05	BRAIDWOOD	0.3g Focused	3.17E-06
SURRY	0.3g Focused	2.02E-05	WOLF CREEK	0.3g Focused	2.95E-06
CATAWBA	0.3g Focused	1.96E-05	QUAD CITIES	0.3g Focused	2.66E-06
MAINE YANKEE	0.3g Full	1.92E-05	FITZPATRICK	0.3g Focused	2.57E-06
LIMERICK	0.3g Focused	1.79E-05	NINE MILE POINT	0.3g Focused	2.57E-06
SUMMER	0.3g Focused	1.62E-05	FARLEY	0.3g Focused	1.02E-06
POINT BEACH	0.3g Focused	1.58E-05			

Table 5-11

RANKINGS, INDICATING PLANT NAMES, OF PEAK (2 TO 10 HZ) MEDIAN PROBABILITY OF EXCEEDING NUREG/CR-0098 SPECTRUM ANCHORED TO 0.3G; 50 0.3G SITES, TWO 0.5G SITES, AND THE PVNGS SITE

Plant Name	Review Type	Hazard	Plant Name	Review Type	Hazard
PILGRIM	0.5g (PRA)	5.68E-05	POINT BEACH	0.3g Focused	4.33E-06
SEABROOK	0.5g (PRA)	2.59E-05	BELLEFONTE	0.3g Focused	4.11E-06
YANKEE ROWE	0.3g Full	1.97E-05	OYSTER CREEK	0.3g Focused	3.50E-06
SEQUOYAH	0.3g Full	1.94E-05	PEACH BOTTOM	0.3g Focused	3.46E-06
NORTH ANNA	0.3g Focused	1.63E-05	BEAVER VALLEY	0.3g Focused	3.23E-06
WATTS BAR	0.3g Focused	1.58E-05	VERMONT YANKEE	0.3g Focused	3.20E-06
PALO VERDE	—	1.27E-05	ARKANSAS	0.3g Full	2.43E-06
HADDAM NECK	0.3g Focused	1.16E-05	GINNA	0.3g Focused	2.38E-06
INDIAN POINT	0.3g Full	1.14E-05	DAVIS BESSE	0.3g Focused	2.36E-06
OCONEE	0.3g Full	1.07E-05	FERMI	0.3g Focused	2.19E-06
LA SALLE	0.3g Focused	1.04E-05	SURRY	0.3g Focused	2.05E-06
MAINE YANKEE	0.3g Full	1.04E-05	BROWNS FERRY	0.3g Focused	1.64E-06
ZION	0.3g Focused	9.15E-06	SUSQUEHANNA	0.3g Focused	1.59E-06
MILLSTONE	0.3g Focused	8.09E-06	BYRON	0.3g Focused	1.48E-06
LIMERICK	0.3g Focused	7.87E-06	WOLF CREEK	0.3g Focused	1.39E-06
CATAWBA	0.3g Focused	7.86E-06	CALVERT CLIFFS	0.3g Focused	1.33E-06
BRUNSWICK	0.3g Focused	7.67E-06	PERRY	0.3g Focused	1.23E-06
SUMMER	0.3g Focused	7.01E-06	DRESDEN	0.3g Focused	1.22E-06
KEWAUNEE	0.3g Focused	6.47E-06	BRAIDWOOD	0.3g Focused	1.17E-06
SALEM	0.3g Focused	5.83E-06	PRAIRIE ISLAND	0.3g Focused	1.17E-06
HOPE CREEK	0.3g Focused	5.83E-06	NINE MILE POINT	0.3g Focused	1.09E-06
VOGTLE	0.3g Focused	5.49E-06	FITZPATRICK	0.3g Focused	1.09E-06
CLINTON	0.3g Focused	5.43E-06	HATCH	0.3g Focused	9.86E-07
MCGUIRE	0.3g Focused	5.04E-06	SHEARON HARRIS	0.3g Focused	8.52E-07
THREE MILE ISLAND	0.3g Focused	4.95E-06	QUAD CITIES	0.3g Focused	5.78E-07
ROBINSON	0.3g Full	4.92E-06	FARLEY	0.3g Focused	1.53E-07
MONTICELLO	0.3g Focused	4.44E-06			

Table 5-12

RANKINGS, INDICATING PLANT NAMES, OF PEAK (2 TO 10 HZ) 85TH-FRACTILE PROBABILITY OF EXCEEDING NUREG/CR-0098 SPECTRUM ANCHORED TO 0.3G; 50 0.3G SITES, TWO 0.5G SITES, AND THE PVNGS SITE

Plant Name	Review Type	Hazard
PILGRIM	0.5g (PRA)	2.65E-04
SEABROOK	0.5g (PRA)	1.01E-04
YANKEE ROWE	0.3g Full	9.71E-05
INDIAN POINT	0.3g Full	7.98E-05
SEQUOYAH	0.3g Full	7.54E-05
WATTS BAR	0.3g Focused	7.04E-05
PALO VERDE	—	6.28E-05
NORTH ANNA	0.3g Focused	5.37E-05
LA SALLE	0.3g Focused	5.17E-05
OCONEE	0.3g Full	4.87E-05
HADDAM NECK	0.3g Focused	4.68E-05
CATAWBA	0.3g Focused	4.40E-05
MAINE YANKEE	0.3g Full	4.39E-05
VOGTLE	0.3g Focused	3.93E-05
BRUNSWICK	0.3g Focused	3.91E-05
ROBINSON	0.3g Full	3.84E-05
CLINTON	0.3g Focused	3.83E-05
ZION	0.3g Focused	3.79E-05
SALEM	0.3g Focused	3.38E-05
HOPE CREEK	0.3g Focused	3.38E-05
KEWAUNEE	0.3g Focused	3.36E-05
MILLSTONE	0.3g Focused	3.15E-05
LIMERICK	0.3g Focused	3.05E-05
SUMMER	0.3g Focused	3.00E-05
OYSTER CREEK	0.3g Focused	2.82E-05
MCGUIRE	0.3g Focused	2.48E-05
PEACH BOTTOM	0.3g Focused	2.45E-05
MONTICELLO	0.3g Focused	2.41E-05
POINT BEACH	0.3g Focused	2.34E-05
SURRY	0.3g Focused	2.03E-05
BEAVER VALLEY	0.3g Focused	2.03E-05
THREE MILE ISLAND	0.3g Focused	1.94E-05
BELLEFONTE	0.3g Focused	1.91E-05
VERMONT YANKEE	0.3g Focused	1.42E-05
GINNA	0.3g Focused	1.27E-05
CALVERT CLIFFS	0.3g Focused	1.16E-05
FERMI	0.3g Focused	1.12E-05
DAVIS BESSE	0.3g Focused	1.04E-05
HATCH	0.3g Focused	9.22E-06
ARKANSAS	0.3g Full	9.06E-06
BROWNS FERRY	0.3g Focused	8.35E-06
PERRY	0.3g Focused	7.83E-06
SUSQUEHANNA	0.3g Focused	7.60E-06
PRAIRIE ISLAND	0.3g Focused	7.09E-06
SHEARON HARRIS	0.3g Focused	6.71E-06
BYRON	0.3g Focused	6.40E-06
DRESDEN	0.3g Focused	6.20E-06
BRAIDWOOD	0.3g Focused	5.98E-06
WOLF CREEK	0.3g Focused	5.75E-06
NINE MILE POINT	0.3g Focused	4.71E-06
FITZPATRICK	0.3g Focused	4.71E-06
QUAD CITIES	0.3g Focused	3.76E-06
FARLEY	0.3g Focused	1.33E-06

Table 5-13

RANKINGS, INDICATING PLANT NAMES, OF AVERAGE (2 TO 10 HZ) MEAN PROBABILITY OF EXCEEDING NUREG/CR-0098 SPECTRUM ANCHORED TO 0.3G; 50 0.3G SITES, TWO 0.5G SITES, AND THE PVNGS SITE

Plant Name	Review Type	Hazard	Plant Name	Review Type	Hazard
PILGRIM	0.5g (PRA)	8.53E-05	MONTICELLO	0.3g Focused	7.19E-06
YANKEE ROWE	0.3g Full	3.78E-05	POINT BEACH	0.3g Focused	6.91E-06
SEABROOK	0.5g (PRA)	2.55E-05	BEAVER VALLEY	0.3g Focused	6.85E-06
PALO VERDE	—	2.20E-05	KEWAUNEE	0.3g Focused	6.30E-06
VOGTLE	0.3g Focused	2.04E-05	MCGUIRE	0.3g Focused	6.15E-06
INDIAN POINT	0.3g Full	1.98E-05	BELLEFONTE	0.3g Focused	5.65E-06
SEQUOYAH	0.3g Full	1.91E-05	THREE MILE ISLAND	0.3g Focused	5.63E-06
HOPE CREEK	0.3g Focused	1.87E-05	HATCH	0.3g Focused	5.55E-06
SALEM	0.3g Focused	1.87E-05	FERMI	0.3g Focused	4.21E-06
CLINTON	0.3g Focused	1.81E-05	VERMONT YANKEE	0.3g Focused	3.89E-06
BRUNSWICK	0.3g Focused	1.79E-05	GINNA	0.3g Focused	3.64E-06
ROBINSON	0.3g Full	1.75E-05	ARKANSAS	0.3g Full	3.15E-06
NORTH ANNA	0.3g Focused	1.65E-05	DAVIS BESSE	0.3g Focused	2.82E-06
WATTS BAR	0.3g Focused	1.65E-05	BROWNS FERRY	0.3g Focused	2.80E-06
HADDAM NECK	0.3g Focused	1.64E-05	PRAIRIE ISLAND	0.3g Focused	2.71E-06
OYSTER CREEK	0.3g Focused	1.62E-05	SUSQUEHANNA	0.3g Focused	2.36E-06
LA SALLE	0.3g Focused	1.58E-05	PERRY	0.3g Focused	2.07E-06
SURRY	0.3g Focused	1.41E-05	BYRON	0.3g Focused	1.79E-06
ZION	0.3g Focused	1.34E-05	SHEARON HARRIS	0.3g Focused	1.74E-06
OCONEE	0.3g Full	1.31E-05	DRESDEN	0.3g Focused	1.61E-06
MILLSTONE	0.3g Focused	1.08E-05	BRAIDWOOD	0.3g Focused	1.40E-06
CATAWBA	0.3g Focused	1.02E-05	WOLF CREEK	0.3g Focused	1.39E-06
LIMERICK	0.3g Focused	9.43E-06	QUAD CITIES	0.3g Focused	1.22E-06
MAINE YANKEE	0.3g Full	9.28E-06	NINE MILE POINT	0.3g Focused	1.16E-06
SUMMER	0.3g Focused	8.77E-06	FITZPATRICK	0.3g Focused	1.15E-06
CALVERT CLIFFS	0.3g Focused	8.20E-06	FARLEY	0.3g Focused	5.25E-07
PEACH BOTTOM	0.3g Focused	7.23E-06			

Table 5-14

RANKINGS, INDICATING PLANT NAMES, OF AVERAGE (2 TO 10 HZ) MEDIAN PROBABILITY OF EXCEEDING NUREG/CR-0098 SPECTRUM ANCHORED TO 0.3G; 50 0.3G SITES, TWO 0.5G SITES, AND THE PVNGS SITE

Plant Name	Review Type	Hazard	Plant Name	Review Type	Hazard
PILGRIM	0.5g (PRA)	2.43E-05	KEWAUNEE	0.3g Focused	1.41E-06
SEABROOK	0.5g (PRA)	8.80E-06	MONTICELLO	0.3g Focused	1.38E-06
YANKEE ROWE	0.3g Full	8.67E-06	BEAVER VALLEY	0.3g Focused	1.21E-06
PALO VERDE	—	7.54E-06	PEACH BOTTOM	0.3g Focused	1.09E-06
SEQUOYAH	0.3g Full	5.87E-06	BELLEFONTE	0.3g Focused	1.03E-06
NORTH ANNA	0.3g Focused	5.15E-06	VERMONT YANKEE	0.3g Focused	9.54E-07
WATTS BAR	0.3g Focused	4.56E-06	SURRY	0.3g Focused	8.61E-07
INDIAN POINT	0.3g Full	3.96E-06	ARKANSAS	0.3g Full	6.88E-07
LA SALLE	0.3g Focused	3.66E-06	GINNA	0.3g Focused	6.36E-07
MAINE YANKEE	0.3g Full	3.42E-06	DAVIS BESSE	0.3g Focused	6.13E-07
BRUNSWICK	0.3g Focused	3.36E-06	FERMI	0.3g Focused	6.06E-07
HADDAM NECK	0.3g Focused	3.32E-06	CALVERT CLIFFS	0.3g Focused	5.39E-07
OCONEE	0.3g Full	3.21E-06	BROWNS FERRY	0.3g Focused	4.60E-07
ZION	0.3g Focused	2.97E-06	SUSQUEHANNA	0.3g Focused	4.30E-07
VOGTLE	0.3g Focused	2.75E-06	HATCH	0.3g Focused	4.15E-07
CATAWBA	0.3g Focused	2.69E-06	PRAIRIE ISLAND	0.3g Focused	3.77E-07
SUMMER	0.3g Focused	2.49E-06	WOLF CREEK	0.3g Focused	3.57E-07
LIMERICK	0.3g Focused	2.46E-06	BYRON	0.3g Focused	3.23E-07
MILLSTONE	0.3g Focused	2.42E-06	PERRY	0.3g Focused	2.98E-07
ROBINSON	0.3g Full	2.40E-06	BRAIDWOOD	0.3g Focused	2.81E-07
SALEM	0.3g Focused	2.31E-06	DRESDEN	0.3g Focused	2.75E-07
HOPE CREEK	0.3g Focused	2.31E-06	FITZPATRICK	0.3g Focused	2.59E-07
CLINTON	0.3g Focused	1.80E-06	NINE MILE POINT	0.3g Focused	2.59E-07
MCGUIRE	0.3g Focused	1.55E-06	SHEARON HARRIS	0.3g Focused	2.30E-07
OYSTER CREEK	0.3g Focused	1.54E-06	QUAD CITIES	0.3g Focused	1.26E-07
THREE MILE ISLAND	0.3g Focused	1.51E-06	FARLEY	0.3g Focused	3.65E-08
POINT BEACH	0.3g Focused	1.44E-06			

Table 5-15

RANKINGS, INDICATING PLANT NAMES, OF AVERAGE (2 TO 10 HZ) 85TH-FRACTILE PROBABILITY OF EXCEEDING NUREG/CR-0098 SPECTRUM ANCHORED TO 0.3G; 50 0.3G SITES, TWO 0.5G SITES, AND THE PVNGS SITE

Plant Name	Review Type	Hazard	Plant Name	Review Type	Hazard
PILGRIM	0.5g (PRA)	1.46E-04	MONTICELLO	0.3g Focused	1.00E-05
YANKEE ROWE	0.3g Full	6.11E-05	POINT BEACH	0.3g Focused	9.48E-06
SEABROOK	0.5g (PRA)	5.59E-05	BEAVER VALLEY	0.3g Focused	8.84E-06
PALO VERDE	—	4.17E-05	KEWAUNEE	0.3g Focused	8.74E-06
INDIAN POINT	0.3g Full	3.84E-05	THREE MILE ISLAND	0.3g Focused	8.73E-06
SEQUOYAH	0.3g Full	3.26E-05	CALVERT CLIFFS	0.3g Focused	8.28E-06
WATTS BAR	0.3g Focused	3.08E-05	BELLEFONTE	0.3g Focused	7.50E-06
NORTH ANNA	0.3g Focused	3.01E-05	VERMONT YANKEE	0.3g Focused	6.29E-06
VOGTLE	0.3g Focused	2.97E-05	HATCH	0.3g Focused	5.62E-06
ROBINSON	0.3g Full	2.91E-05	GINNA	0.3g Focused	4.99E-06
BRUNSWICK	0.3g Focused	2.36E-05	FERMI	0.3g Focused	4.69E-06
CLINTON	0.3g Focused	2.22E-05	DAVIS BESSE	0.3g Focused	4.28E-06
LA SALLE	0.3g Focused	2.11E-05	ARKANSAS	0.3g Full	3.74E-06
CATAWBA	0.3g Focused	2.08E-05	BROWNS FERRY	0.3g Focused	3.47E-06
MAINE YANKEE	0.3g Full	2.03E-05	SUSQUEHANNA	0.3g Focused	3.44E-06
SALEM	0.3g Focused	1.87E-05	PRAIRIE ISLAND	0.3g Focused	2.76E-06
HOPE CREEK	0.3g Focused	1.87E-05	PERRY	0.3g Focused	2.65E-06
OCONEE	0.3g Full	1.83E-05	SHEARON HARRIS	0.3g Focused	2.28E-06
HADDAM NECK	0.3g Focused	1.81E-05	WOLF CREEK	0.3g Focused	2.12E-06
SUMMER	0.3g Focused	1.66E-05	BYRON	0.3g Focused	2.02E-06
OYSTER CREEK	0.3g Focused	1.63E-05	NINE MILE POINT	0.3g Focused	1.97E-06
ZION	0.3g Focused	1.61E-05	FITZPATRICK	0.3g Focused	1.96E-06
LIMERICK	0.3g Focused	1.38E-05	DRESDEN	0.3g Focused	1.95E-06
SURRY	0.3g Focused	1.38E-05	BRAIDWOOD	0.3g Focused	1.87E-06
MILLSTONE	0.3g Focused	1.33E-05	QUAD CITIES	0.3g Focused	1.29E-06
MCGUIRE	0.3g Focused	1.31E-05	FARLEY	0.3g Focused	5.66E-07
PEACH BOTTOM	0.3g Focused	1.14E-05			

Section 6
CONCLUSIONS AND RECOMMENDATIONS

This report has presented the methods and results of comparisons that achieve a technically supportable basis for defining an appropriate RLE level to be used in the IPEEE study of the Palo Verde Nuclear Generating Station. The approach and comparisons adopted follow closely the basis for binning described in NUREG-1407; thus, it is insured that the analysis conducted here is appropriate and consistent with the manner in which plants were originally established in the 0.3g bin. In addition, a wider variety of hazard comparisons have been included to demonstrate the robustness of the study conclusions. As is clearly demonstrated in this section, these comparisons consistently support the conclusion that a 0.3g RLE assignment is appropriate for the Palo Verde site.

6.1 SUMMARY OF KEY RESULTS

The main results of the analyses which lead to the 0.3g RLE assessment for Palo Verde are summarized below:

- The composite probability of exceeding the 0.3g NUREG/CR-0098 spectrum, developed and used in NUREG-14C7 as the major basis for plant binning, is a logical parameter on which to compare seismic hazards and to establish an RLE decision. Consistent with the NUREG-1407 approach, therefore, this study has considered the composite probability of exceedance and three additional scalar measures of the probability of exceeding the 0.3g NUREG/CR-0098 spectrum. For the PVNGS site, all of these scalar exceedance probabilities lie consistently within the range of corresponding values obtained for central and eastern U.S. plants in the 0.3g focused-scope or full-scope SMA bin. For the composite exceedance probability, the rankings for PVNGS range from 4-of-51 to 5-of-51; for the alternate-composite exceedance probability, all rankings are 2-of-51; for the peak exceedance probability (over 2 to 10 Hz), the rankings for PVNGS vary from 4-of-51 to 5-of-51; and for the average exceedance probability (over 2 to 10 Hz), all rankings are 2-of-51. Therefore, measures of probabilities of exceeding the 0.3g NUREG/CR-0098 spectrum demonstrate the PVNGS site hazard to be similar to that at plant sites east of the Rocky Mountains that are in the 0.3g RLE bin.

- For the PVNGS site, all scalar measures derived from probabilities of exceeding the NUREG/CR-0098 (median, 5%-damped) spectrum anchored to 0.3g PGA lie consistently below the range of corresponding values obtained for the two central and eastern U.S. plants in the 0.5g (PRA) bin. In other words, comparisons of all statistics of each of the four measures of probability of exceeding the 0.3g NUREG/CR-0098 spectrum produce a ranking of 3 for PVNGS among the 0.5g plants. Hence, the seismic hazard at Palo Verde is unlike (i.e., consistently lower than) that for CEUS plants assigned to the 0.5g RLE (PRA) bin.

- Although NUREG-1407 utilized the probability of exceedance of the 0.3g NUREG/CR-0098 spectrum as the major determinator of the RLE binning assignment, it is also logical to examine the probability of exceeding the 0.5g NUREG/CR-0098 spectrum as a determinator of the appropriate RLE assignment. Importantly, the plants which are most likely to be exposed to ground motions in excess of the 0.5g NUREG/CR-0098 spectrum would be the plants most likely to benefit from a capacity evaluation against the 0.5g NUREG/CR-0098 spectrum. This study, therefore, has also compared the likelihood of exceeding the 0.5g NUREG/CR-0098 spectrum as a means to test whether or not the Palo Verde site would have a significant exposure, relative to other plants, at extremely severe ground-motion levels. Again, four separate hazard measures were utilized to evaluate the likelihood of exceeding the 0.5g NUREG/CR-0098 spectrum, and again, each of the four measures clearly shows the Palo Verde hazard to be similar to that at plant sites east of the Rocky Mountains in the 0.3g RLE bin. A comparison of relative plant rankings based on probabilities of exceeding the 0.3g and 0.5g spectra show, in fact, a more favorable ranking for the PVNGS site as the level/severity of the motion is increased. This observation suggests that severe earthquake events beyond 0.3g become (increasingly) a greater concern for the other CEUS sites than for the Palo Verde site.

- In addition to relative comparisons of probabilities of exceeding the 0.3g NUREG/CR-0098 spectrum, Appendix A of NUREG-1407 considered that inclusion in the 0.5g RLE bin would not be supported unless the <u>absolute</u> level of hazard was high enough to warrant inclusion in this bin. Based on arguments relating to approximate estimates of seismically induced core-damage frequency, the NRC concluded that inclusion of a plant in the 0.5g RLE would be supported only if the mean or upper-bound composite annual probability of exceeding the 0.3g NUREG/CR-0098 spectrum was consistently greater than 1.0×10^{-4} and the median composite annual likelihood of exceeding the 0.3g NUREG/CR-0098 spectrum was greater than 1.0×10^{-5}. From the computations in this study, the mean and 85th-fractile results for Palo Verde are

shown to be significantly less than 1.0×10^{-4}, and the median results are seen to be modestly less than 1.0×10^{-5}, meaning that a 0.5g RLE assessment would not be supported for Palo Verde.

- For the PVNGS site, values of uniform-hazard peak spectral acceleration (across the 2 to 10 Hz frequency range) lie within the upper range of corresponding values obtained for central and eastern U.S. plants in the 0.3g focused-scope or full-scope SMA bin. In addition, values of average spectral acceleration (over 2 to 10 Hz) lie effectively within the upper range of corresponding values obtained for the 0.3g plants. Hence, measures of uniform-hazard spectral acceleration for the PVNGS site are similar to measures of hazard at plant sites east of the Rocky Mountains in the 0.3g RLE bin.

The above results support the requirement in NUREG–1407 of demonstrating that the hazard at Palo Verde is similar to the hazard at plant sites east of the Rocky Mountains in the 0.3g bin. They also show the hazard at Palo Verde to be lower than the hazard at CEUS plant sites in the 0.5g RLE bin. In addition to these points, and related to procedures implemented in NUREG–1407 to distinguish among 0.3g full-scope and focused-scope plants, the following observations are also noted:

- For the PVNGS site, scalar probabilities of exceeding the seismic design basis are indistinguishable from the lower range of results for the 0.3g focused-scope plants. The comparative rankings (ranging from 32-of-44 to 35-of-44) are even more favorable than those obtained above (for probabilities of exceeding the NUREG/CR–0098 spectrum) because of the greater level of conservatism in the seismic design basis for PVNGS compared to the other plants.

  These comparisons verify that PVNGS is designed to a high seismic capacity, relative to the seismic hazard in the area. The fact that the plant systems, structures, and equipment at PVNGS have comparatively greater design capacities (relative to hazard) means simply that they are more likely to be more capable of resisting a severe earthquake than many other CEUS plants in the 0.3g bin. This greater ability to resist severe earthquakes gives PVNGS a major advantage in coping with a potential severe-accident earthquake. Because the probabilities of exceeding PVNGS's seismic design are so low compared to other plants, PVNGS would be among the plants least likely to benefit from a full-scope seismic margins evaluation. Clearly, rather than evaluation of component design capacities and design margins, the greatest benefit of IPEEE evaluation of PVNGS will be achieved simply by checking for possible unusual or spurious conditions (e.g., inadequate anchorage, potential for adverse physical interactions, etc.), as can be readily and effectively accomplished in the plant walkdown alone.

6.2 SUMMARY AND BASIS OF RLE CONCLUSION FOR PALO VERDE

Based upon the set of binning procedures outlined in NUREG-1407, the results of this study support placing the PVNGS site in the 0.3g RLE bin, for the following reasons:

- As discussed in Section 5.3.2, relative (plant-to-plant) comparisons of the PVNGS composite probability of exceeding the 0.3g NUREG/CR-0098 spectrum indicate that the PVNGS hazard lies within the range of hazards for CEUS plants found in the existing 0.3g bin.

- As shown in Figures A-7 to A-9, the mean and 85th-fractile composite probabilities of exceeding the 0.3g spectrum are both considerably less than the absolute level of 10^{-4}, and the corresponding median composite probability is notably lower than the 10^{-5} threshold.

- As indicated in Table 5.2, all other comparison bases also clearly verify that the seismic hazard at the PVNGS site is consistent with the range of hazards for plants found within the existing 0.3g bin. In addition, Table 5.3 indicates that the seismic hazard at the PVNGS site is lower than the range of hazards for CEUS plants in the 0.5g bin.

- Core-damage frequency is often used as a gauge to demonstrate that a plant poses no undue risk to the public health and safety, a key objective of severe-accident policy. Seismically induced core-damage frequencies can be estimated with reasonable accuracy from seismic hazard curves and a plant seismic-margin capacity. In the case of PVNGS, if seismic margin is demonstrated in the IPEEE at an RLE of 0.3g, it can be stated (based on PRA-type analyses conducted in this study) that the mean seismically induced core-damage frequency should be less than 7.0×10^{-6}. This value of mean core-damage frequency is extremely low with respect to results for existing plants. Hence, conducting the IPEEE at PVNGS for an RLE value greater than 0.3g would be unnecessary from the perspective of verifying that the plant seismic risk is adequately low.

On the present basis, therefore, these results show that implementation of the default 0.5g RLE as assigned in NUREG-1407 for PVNGS would not be justified and would introduce an unwarranted level of conservatism in the review process.

These conclusions are based on considerations of similarity in probabilistic hazard results. Deterministic judgment, however, would also appear to support these conclusions. In particular, guidelines for selecting seismic margin earthquake (SME) levels in the EPRI seismic

margins methodology (1) specify that "for plants with safe shutdown earthquake (SSE) levels of about 0.2g or lower, it is recommended that the trial SME level be set at about 0.3g." Based on extensive seismological studies of the PVNGS site, the SSE value has been determined as 0.2g. On an independent basis, therefore, an earthquake review level selection of 0.3g would be confirmed.

In addition, implementing the approach described in NUREG-1407 for delineating among full-scope and focused-scope 0.3g plants, PVNGS would apparently qualify as a 0.3g focused-scope site. NUREG-1407 precludes the exclusive use of focused-scope procedures in the IPEEE analysis of PVNGS. It is considered worthwhile, however, that the use of focused-scope procedures (on a non-exclusive basis) be pursued where found to be appropriate. In particular, results of the first IPEEE analysis, based on 0.3g full-scope SMA application for a single reactor unit, would be used as a basis for judging the applicability and adequacy of focused-scope procedures at the remaining two reactor units, and such procedures would be implemented as appropriate at these units.

The above recommended guidelines are sensitive to a number of factor, most substantially, the seismic hazard results and (to a lesser extent) the procedures used for weighting these results. Therefore, this study's conclusions should be considered as contingent upon these factors. Having stated this caveat, however, it is important to note that past RLE assessments for PVNGS have already been made considering a number of past revisions to the seismic hazard results. The 0.3g RLE conclusion for PVNGS has been shown to be consistently robust with respect to these revisions, thus consistently refuting the NUREG-1407 default assignment of PVNGS into a 0.5g RLE category. In addition, the 0.3g RLE conclusion has been shown to be consistently robust across numerous parameters used to measure seismic hazard. It is considered unlikely, therefore, that any future revisions to the seismic hazard study for PVNGS will alter the 0.3g RLE conclusion.

6.3 REFERENCES

1. R. D. Campbell, D. A. Wesley, B. F. Henley, J. J. Johnson, R. P. Kennedy, D. R. Buttemer, T. McIntyre, D. Bley, Y. Moriwaki, I. M. Idriss, C. Chang, W. Shoemaker, and D. Kulla. *A Methodology for Assessment of Nuclear Power Plant Seismic Margin.* Technical Report NP 6041, Electric Power Research Institute, August 1988.

Appendix A

COMPARISONS OF PROBABILITIES OF EXCEEDING NUREG/CR-0098 SPECTRA

This appendix presents results of probabilities of exceeding the NUREG/CR-0098 median, 5%-damped spectrum. Exceedance-probability spectra are provided for the Palo Verde site and for 50 nuclear power plant locations in the central and eastern United States. The exceedance probabilities are determined as outlined in Section 4, and are computed for the reference NUREG/CR-0098 spectrum anchored to PGA levels of 0.3g and 0.5g. Scalar measures of exceedance probabilities have been derived from the exceedance-probability spectra; the scalar measures include composite probability of exceedance, alternate composite probability of exceedance, peak exceedance probability over the vibrational-frequency range of 2.0 to 10.0 Hz, and exceedance probability averaged over the same frequency range (see Section 4 for more-detailed definitions of these measures). In all cases (for exceedance-probability spectra or for derived scalar measures) comparisons are provided for the mean, median, and 85th-fractile hazards.

Hazard results for the 50 central and eastern U.S. sites are based on the EPRI methodology. The 50 sites are comprised of the 0.3g full-scope and focused-scope plants for which EPRI hazard results have been obtained; seven of these plants are full-scope plants, and the remaining 43 are focused-scope plants.

Figures A-1 to A-3 present, respectively, spectra of the mean, median, and 85th-fractile probabilities of exceeding the median NUREG/CR-0098 5%-damped spectrum anchored to a level of 0.3g. The graphs in Figures A-4 to A-6 present similar results for a PGA level of 0.5g.

[In these spectral plots, results of probabilities of exceeding PGA are indicated by horizontal lines from 65.0 to 100.0 Hz. Consistent with results produced from the seismic hazard investigation for PVNGS and other plants, spectra have not been computed nor plotted over the frequency range of 25 to 65 Hz. To estimate how the exceedance-probability spectrum varies over this frequency range for PVNGS, simply connect the point at 25 Hz to a point at 33 Hz that matches the PGA, and then extend a horizontal line across to 65 Hz. For central/eastern U.S. sites, extend the spectrum linearly beyond 25 Hz to 35 Hz, and then

connect the resulting point at 35 Hz to the PGA value at 65 Hz. (Note, the NUREG/CR-0098 spectrum varies linearly from 8 Hz to only 33 Hz [where it then meets the PGA]; i.e., it does not extend linearly out to 35 Hz as assumed here. Consequently, the peak exceedance probability produced in this approximate procedure will be slightly overestimated).]

Figures A-7 to A-12 present plots of ordered composite exceedance probability. Here, each ordered plot presents a comparison of scalar measures corresponding to the respective comparisons of exceedance probability spectra just described for Figures A-1 to A-6, where the NUREG/CR-0098 median spectral shape is used as the basis for the transformation from ground motions to probabilities.

Figures A-13 to A-18 present plots of ordered alternate-composite exeedance probability. Again, each ordered plot presents a comparison of scalar measures corresponding to the respective comparisons of exceedance probability spectra described for Figures A-1 to A-6.

Figures A-19 to A-24 and Figures A-25 to A-30 present, respectively, plots of ordered peak and averaged exceedance probability over the vibrational frequency range of 2 to 10 Hz. Each of these sets of plots also correspond to each of the six comparisons noted earlier (i.e., for cases of the 0.3g spectrum and mean, median, 85th-fractile hazards, and the 0.5g spectrum with mean, median, and 85th-fractile hazards).

The plots presented in this appendix support the comparisons and observations made in Section 5 of this report, and provide the basis for developing the plant rankings indicated in Table 5-2.

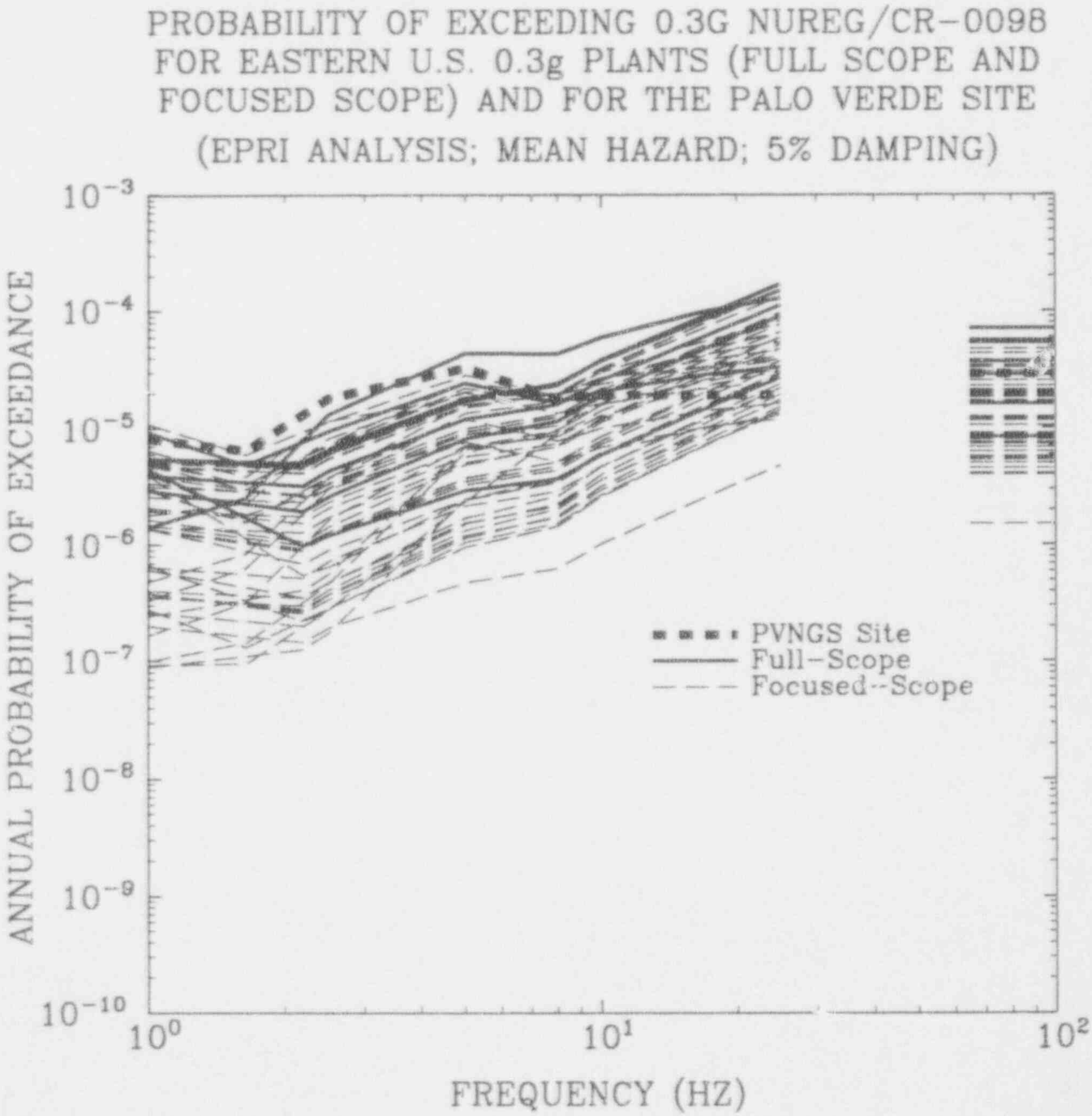


Figure A-1. Mean probabilities of exceeding the NUREG/CR-0098 median, 5%-damped spectrum anchored to 0.3g: comparison of results for the Palo Verde site with similar results for 50 full scope and focused-scope 0.3g plants in the central and eastern U.S.

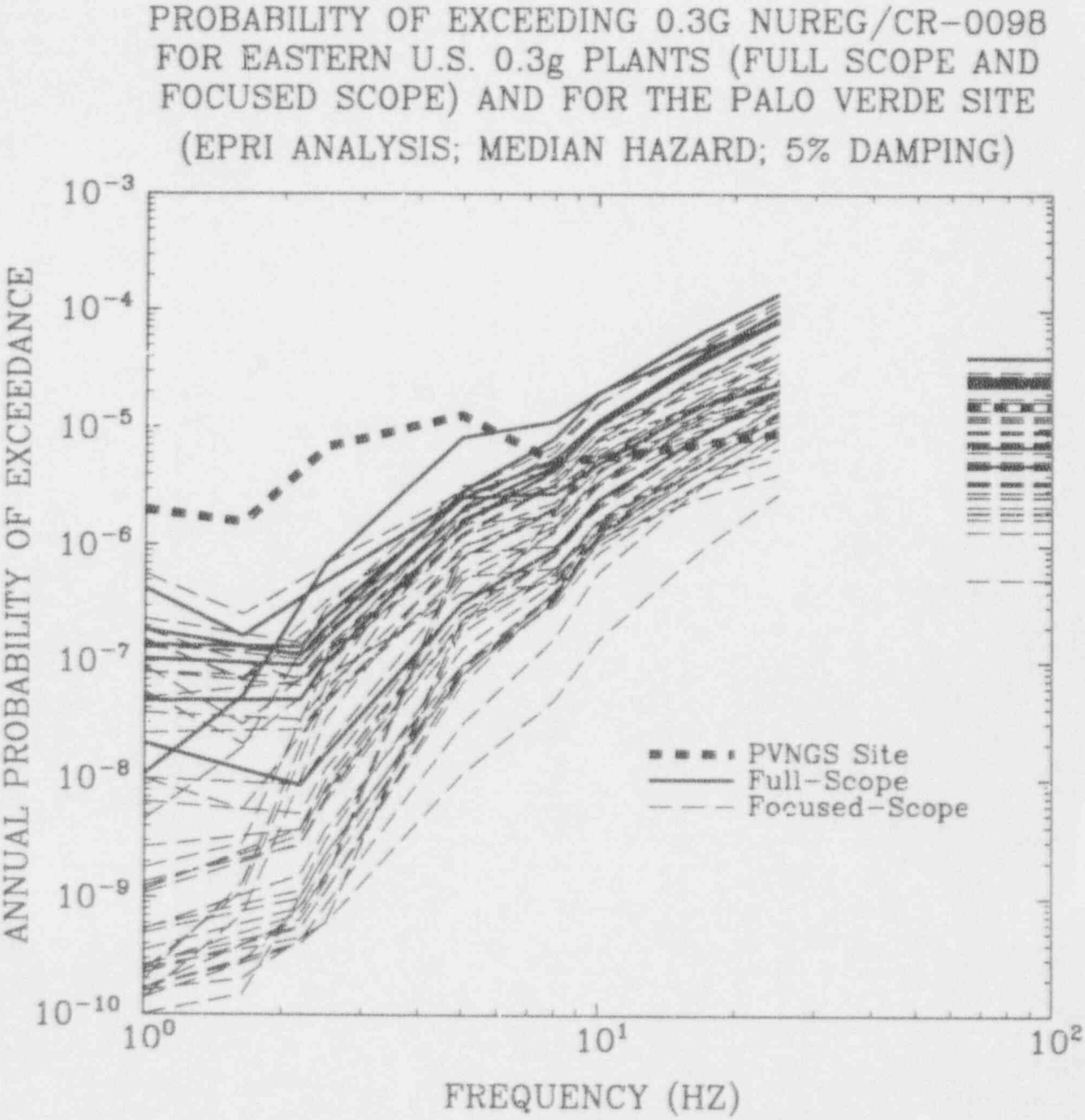


Figure A-2. Median probabilities of exceeding the NUREG/CR-0098 median, 5%-damped spectrum anchored to 0.3g: comparison of results for the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

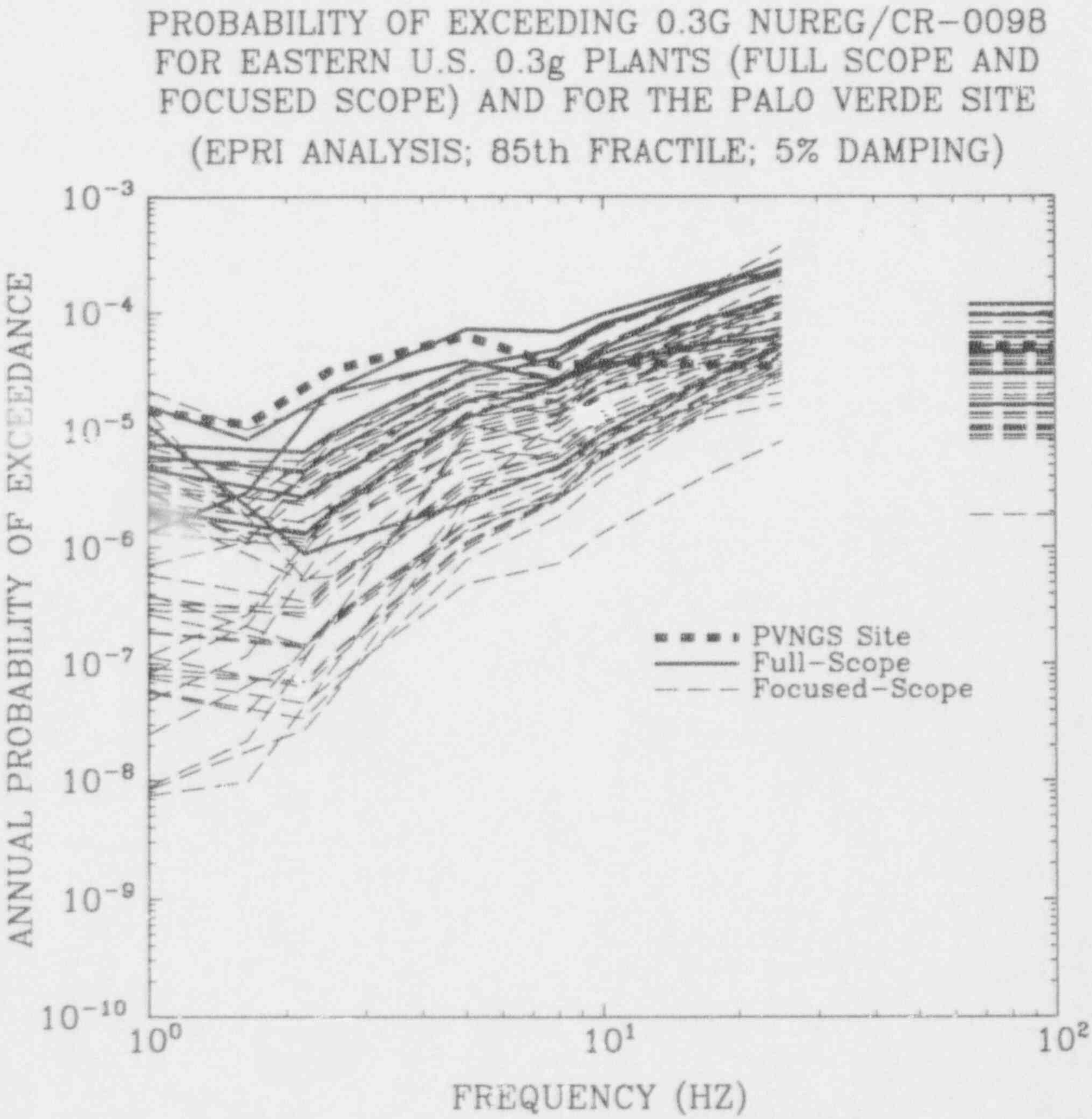


Figure A-3. 85th-fractile probabilities of exceeding the NUREG/CR-0098 median, 5%-damped spectrum anchored to 0.3g: comparison of results for the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

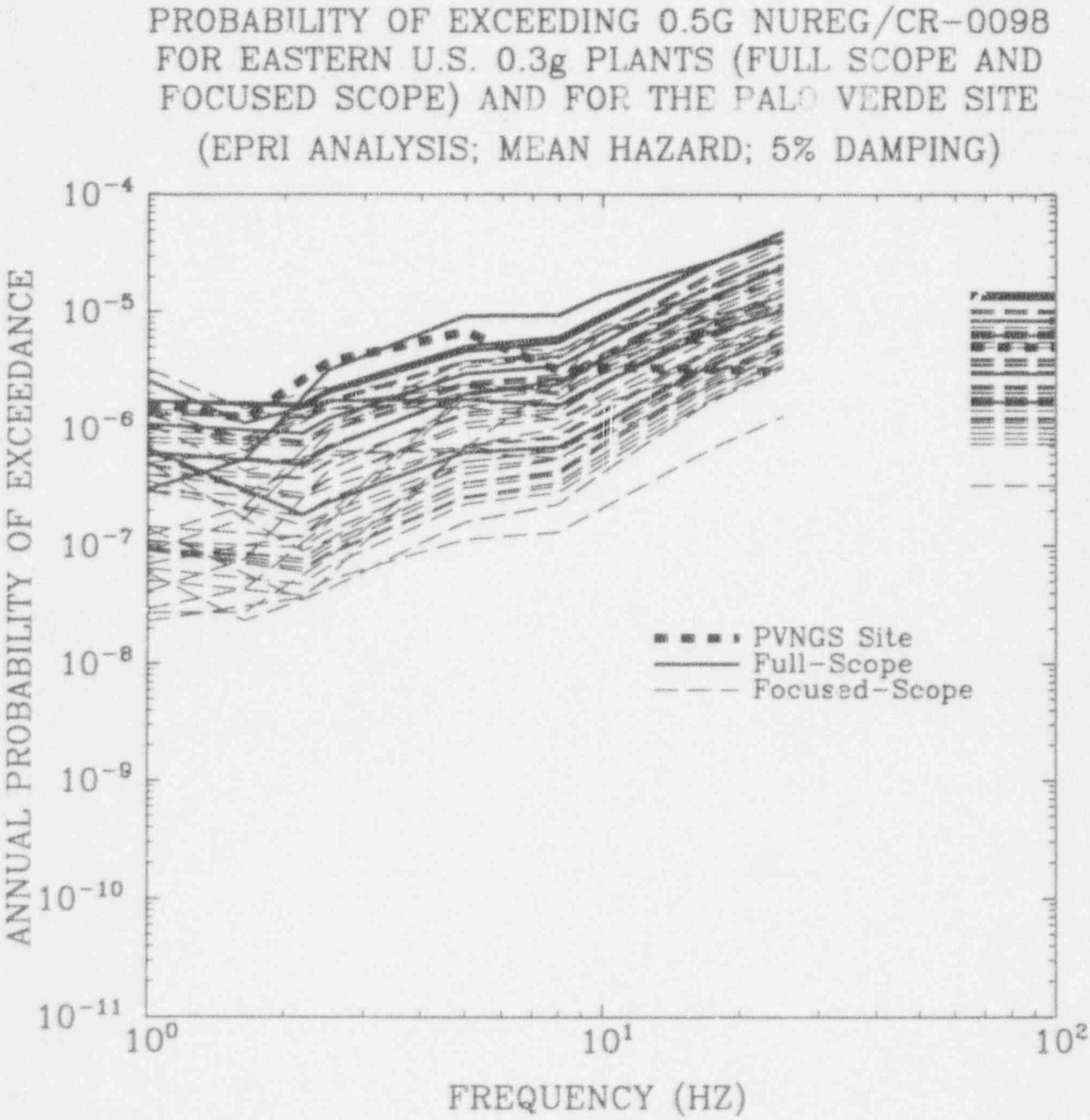


Figure A-4. Mean probabilities of exceeding the NUREG/CR-0098 median, 5%-damped spectrum anchored to 0.5g: comparison of results for the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

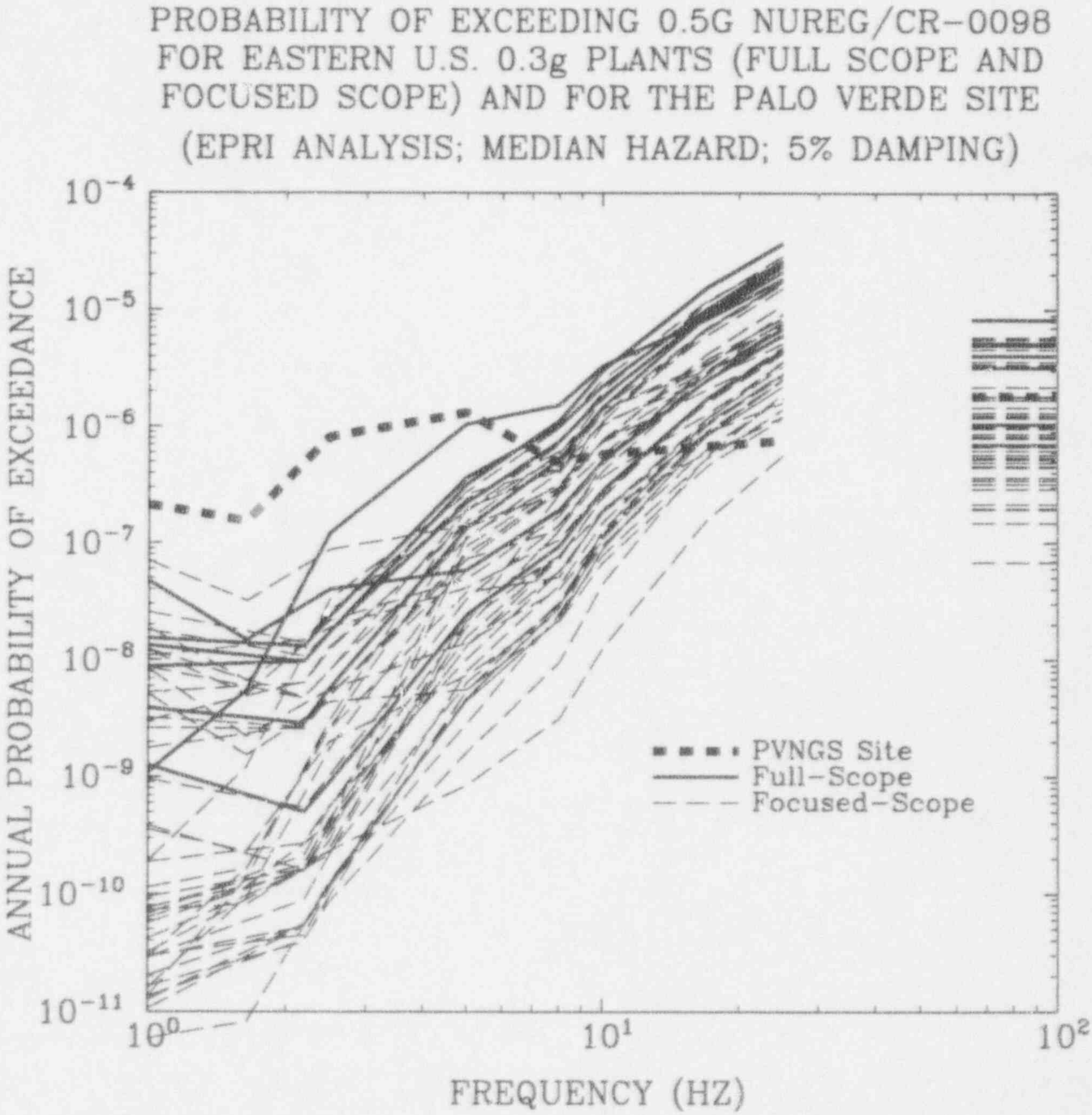


Figure A-5. Median probabilities of exceeding the NUREG/CR-0098 median, 5%-damped spectrum anchored to 0.5g: comparison of results for the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

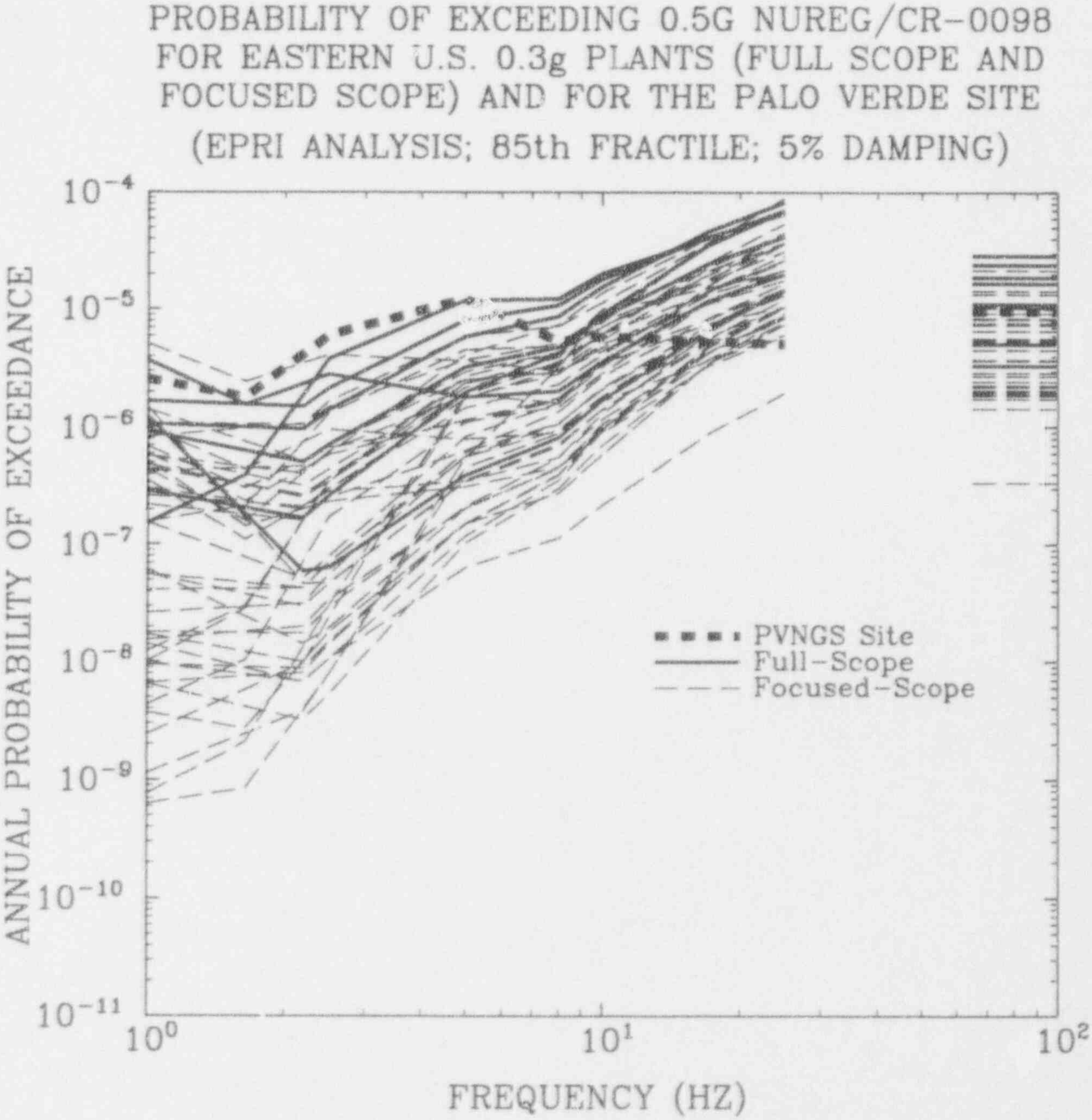


Figure A-6. 85th-fractile probabilities of exceeding the NUREG/CR-0098 median, 5%-damped spectrum anchored to 0.5g: comparison of results for the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

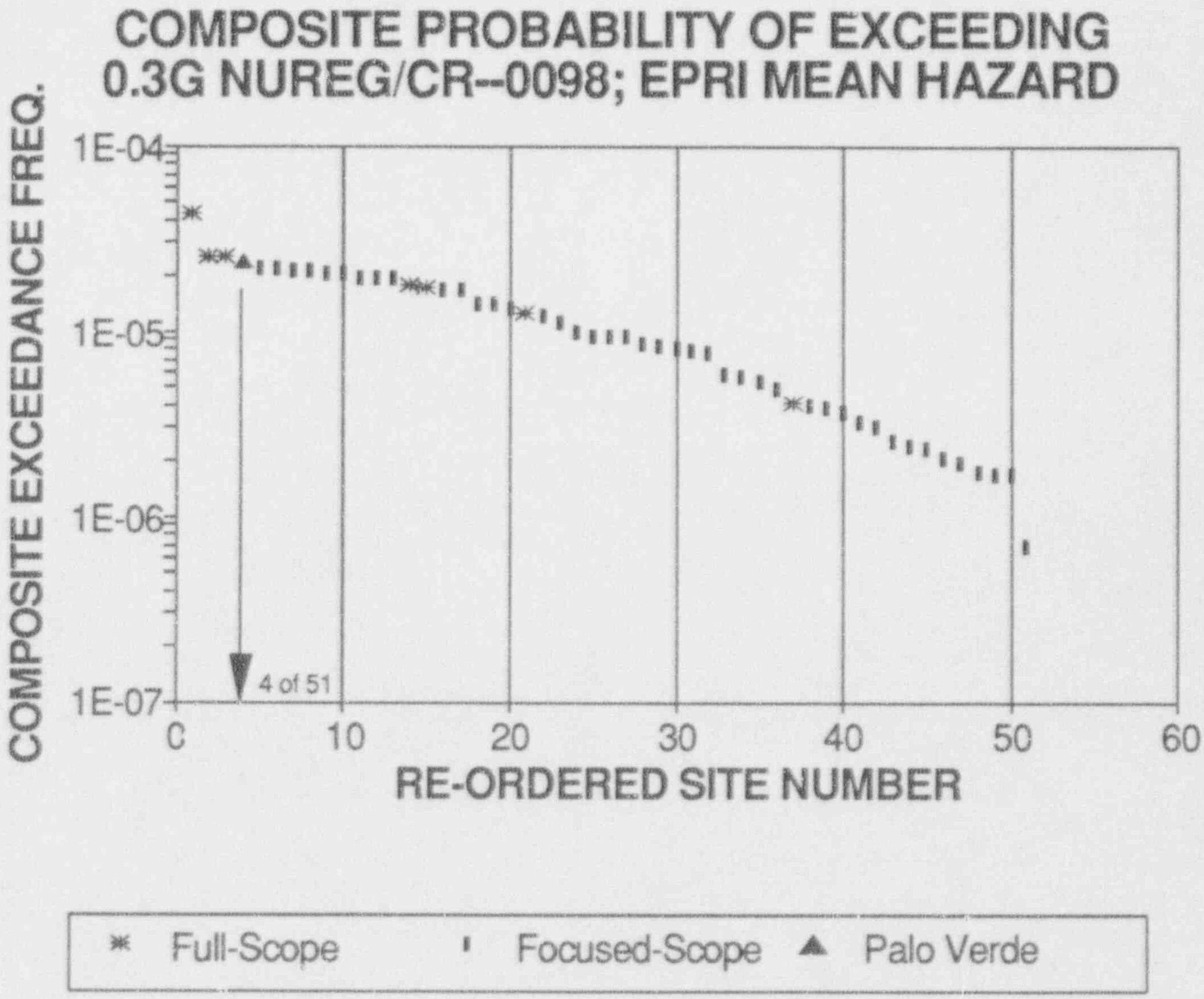


Figure A-7. Comparison of the composite mean probability of exceeding the NUREG/CR-0098 median, 5%-damped spectrum anchored to 0.3g: comparison of results for the the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

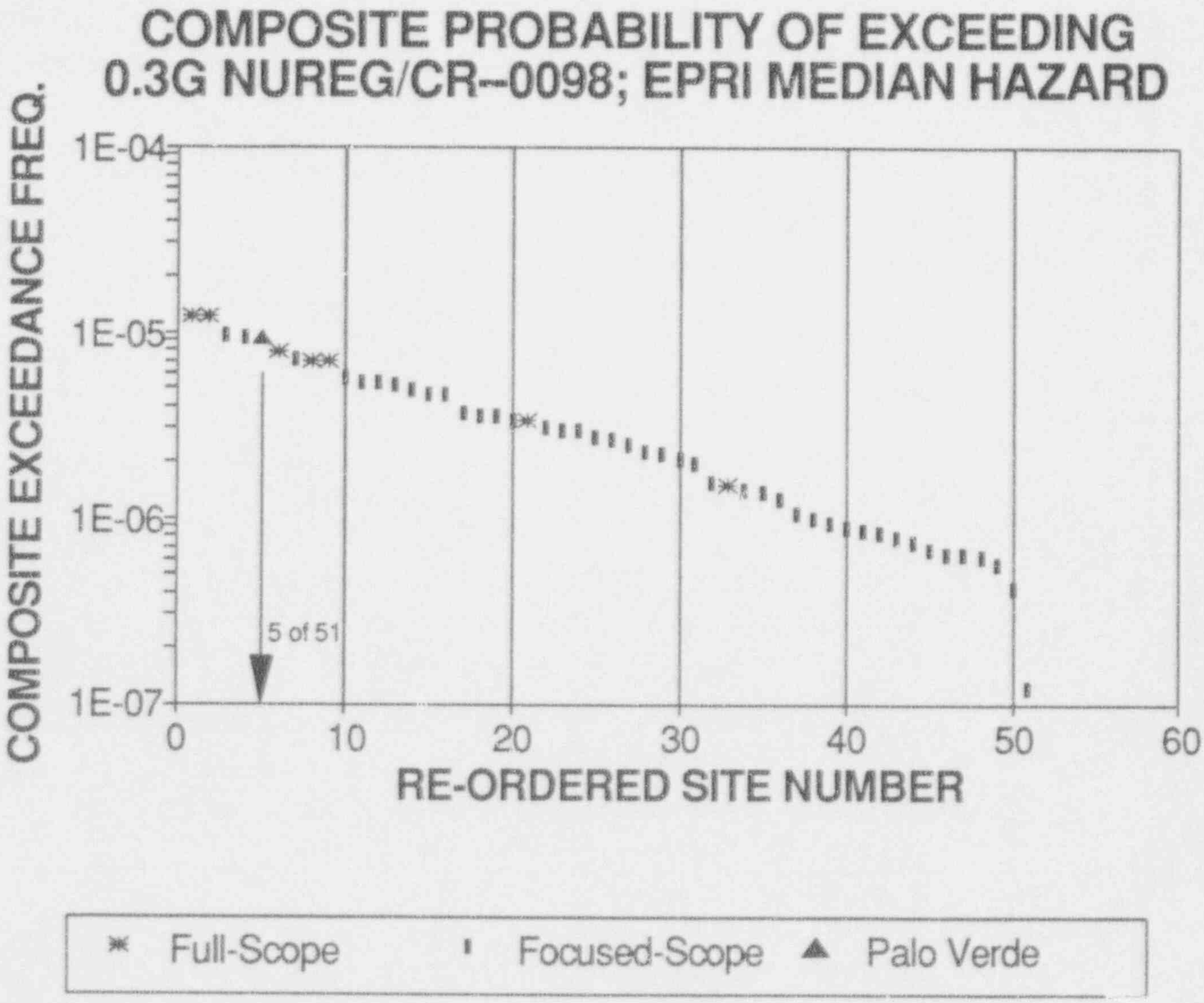


Figure A-8. Comparison of the composite median probability of exceeding the NUREG/CR-0098 median, 5%-damped spectrum anchored to 0.3g: comparison of results for the the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

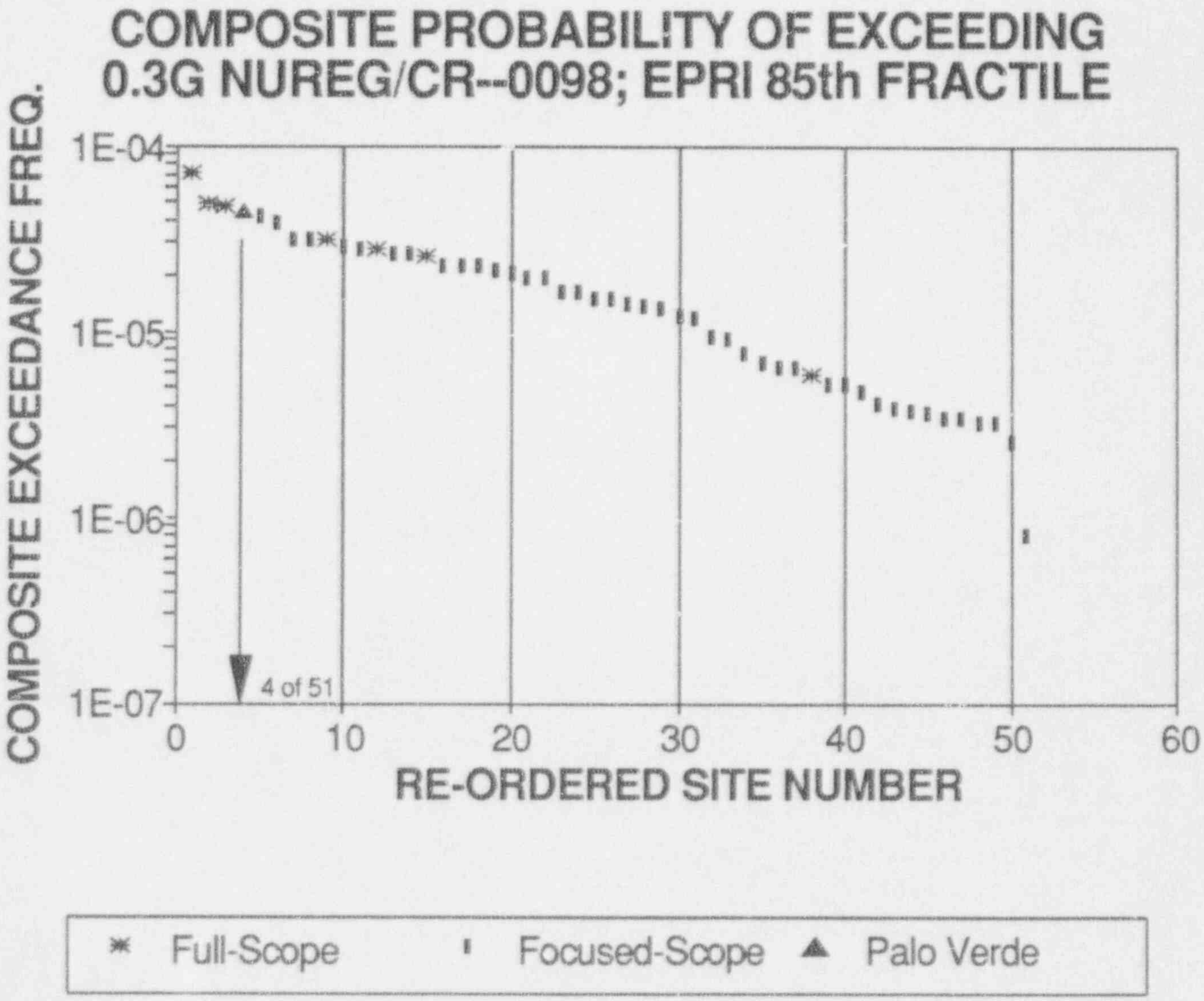


Figure A-9. Comparison of the composite 85th-fractile probability of exceeding the NUREG/CR-0098 median, 5%-damped spectrum anchored to 0.3g: comparison of results for the the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

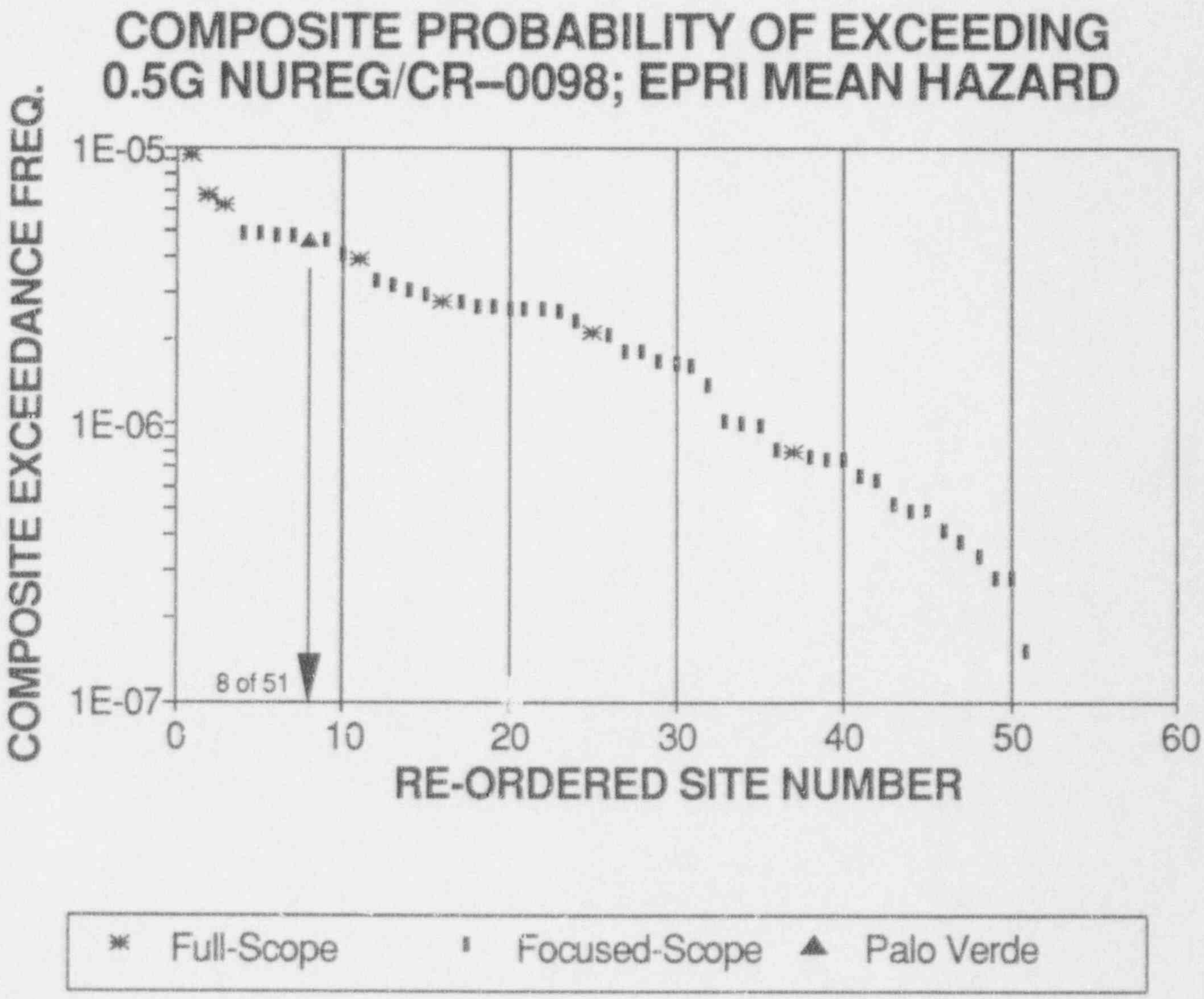


Figure A-10. Comparison of the composite mean probability of exceeding the NUREG/CR-0098 median, 5%-damped spectrum anchored to 0.5g: comparison of results for the the Palo Verde site with simiiar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

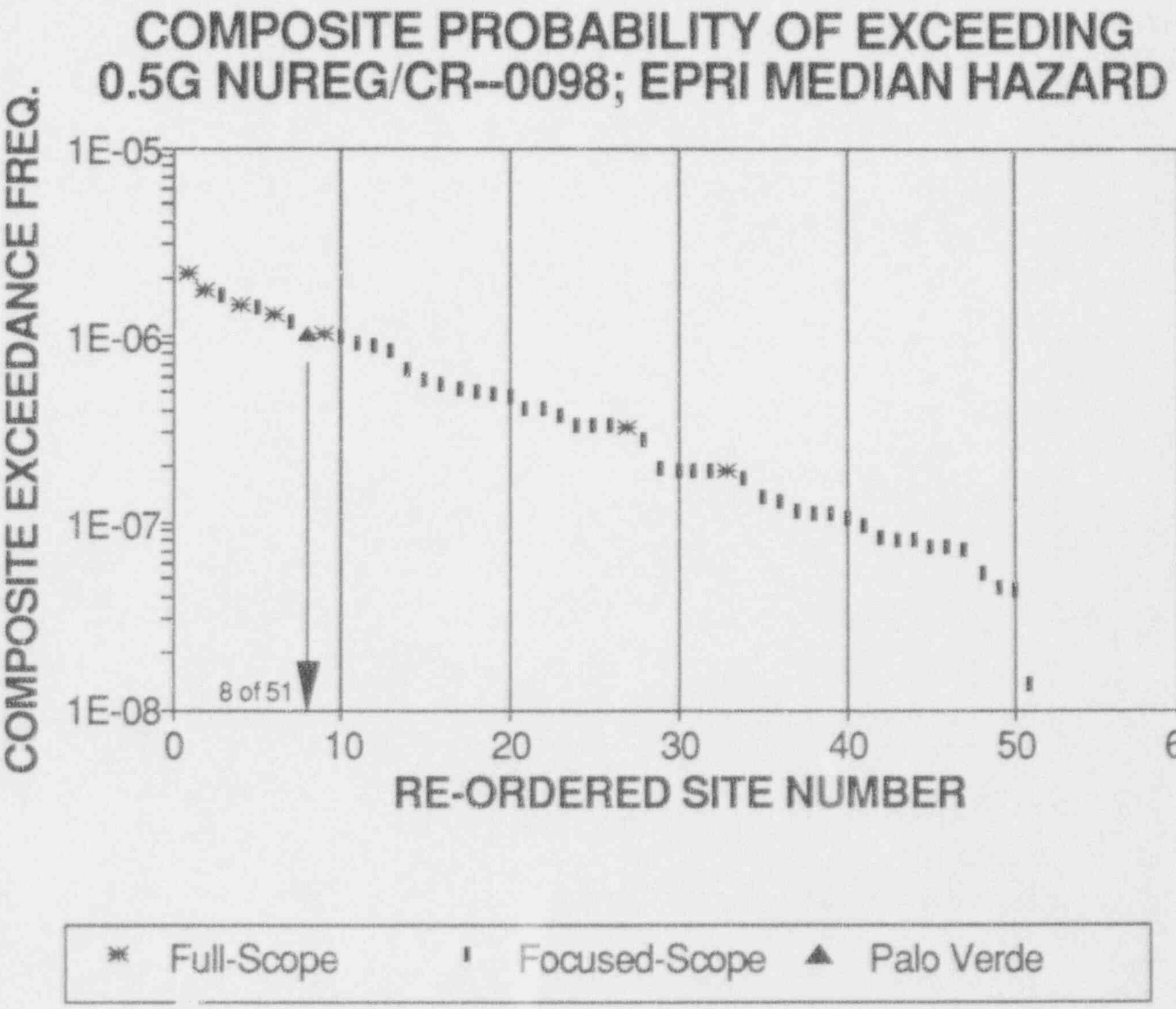


Figure A-11. Comparison of the composite median probability of exceeding the NUREG/CR-0098 median, 5%-damped spectrum anchored to 0.5g: comparison of results for the the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

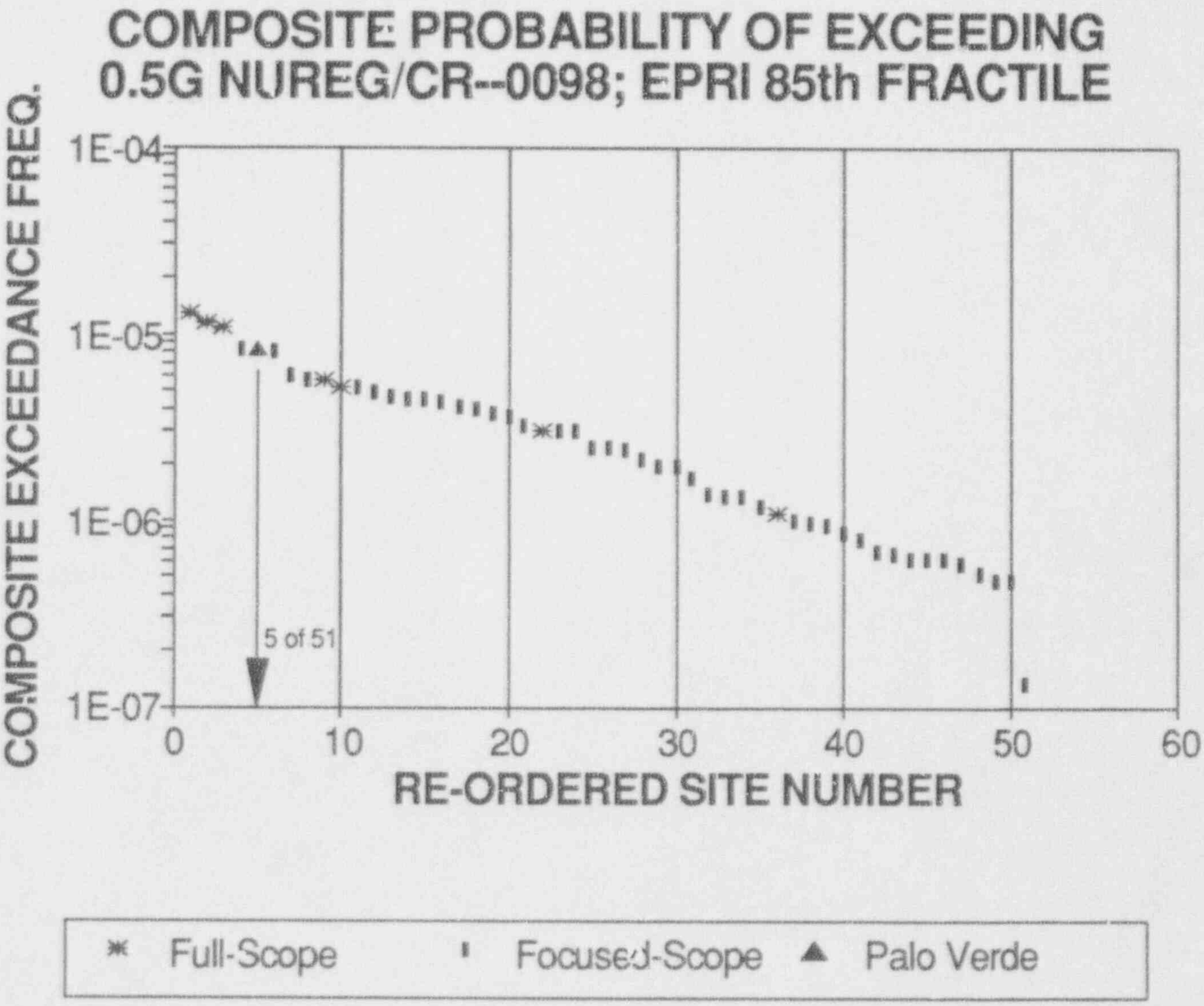


Figure A-12. Comparison of the composite 85th-fractile probability of exceeding the NUREG/CR-0098 median, 5%-damped spectrum anchored to 0.5g: comparison of results for the the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

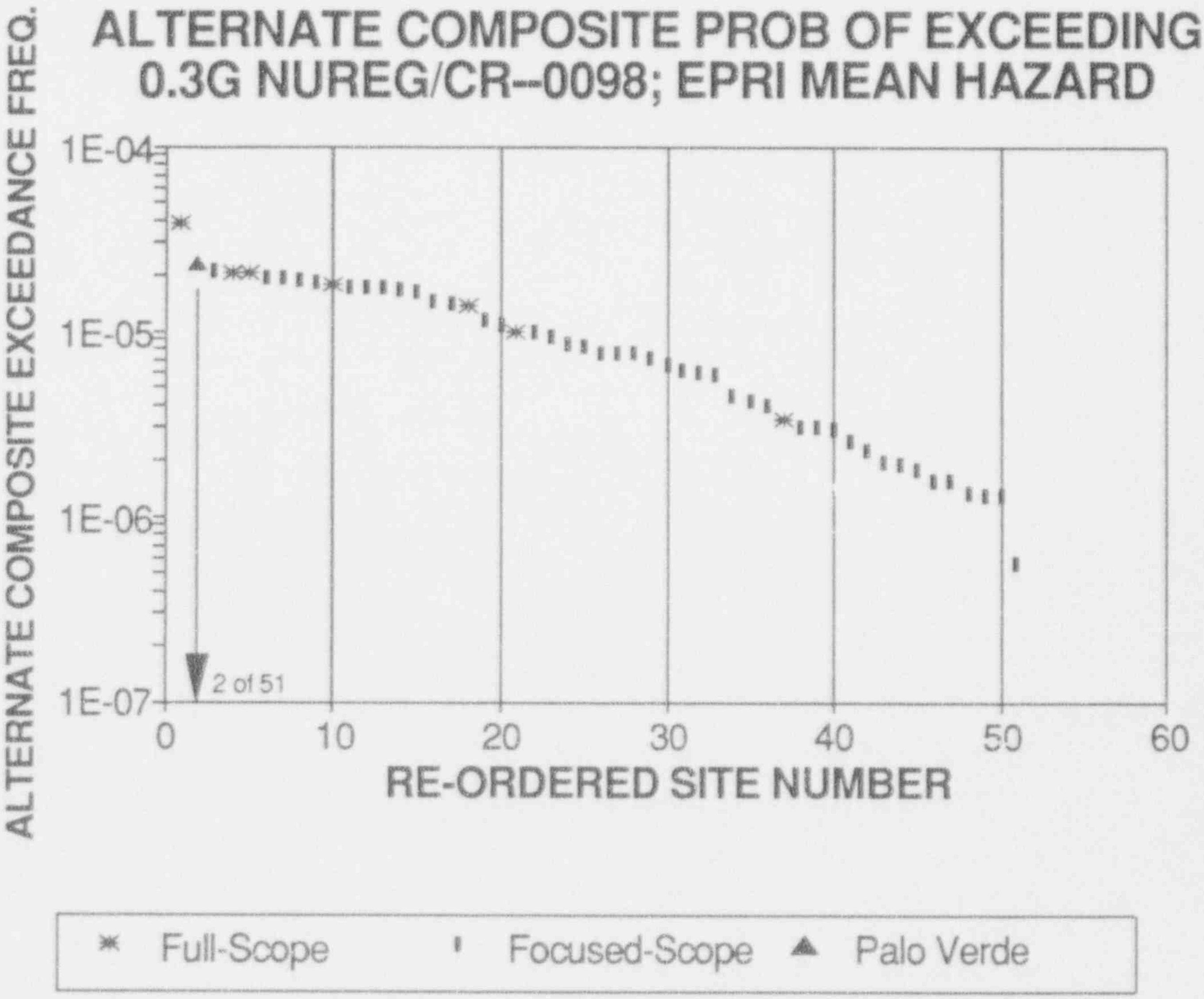


Figure A-13. Comparison of the alternate-composite mean probability of exceeding the NUREG/CR-0098 median, 5%-damped spectrum anchored to 0.3g: comparison of results for the the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

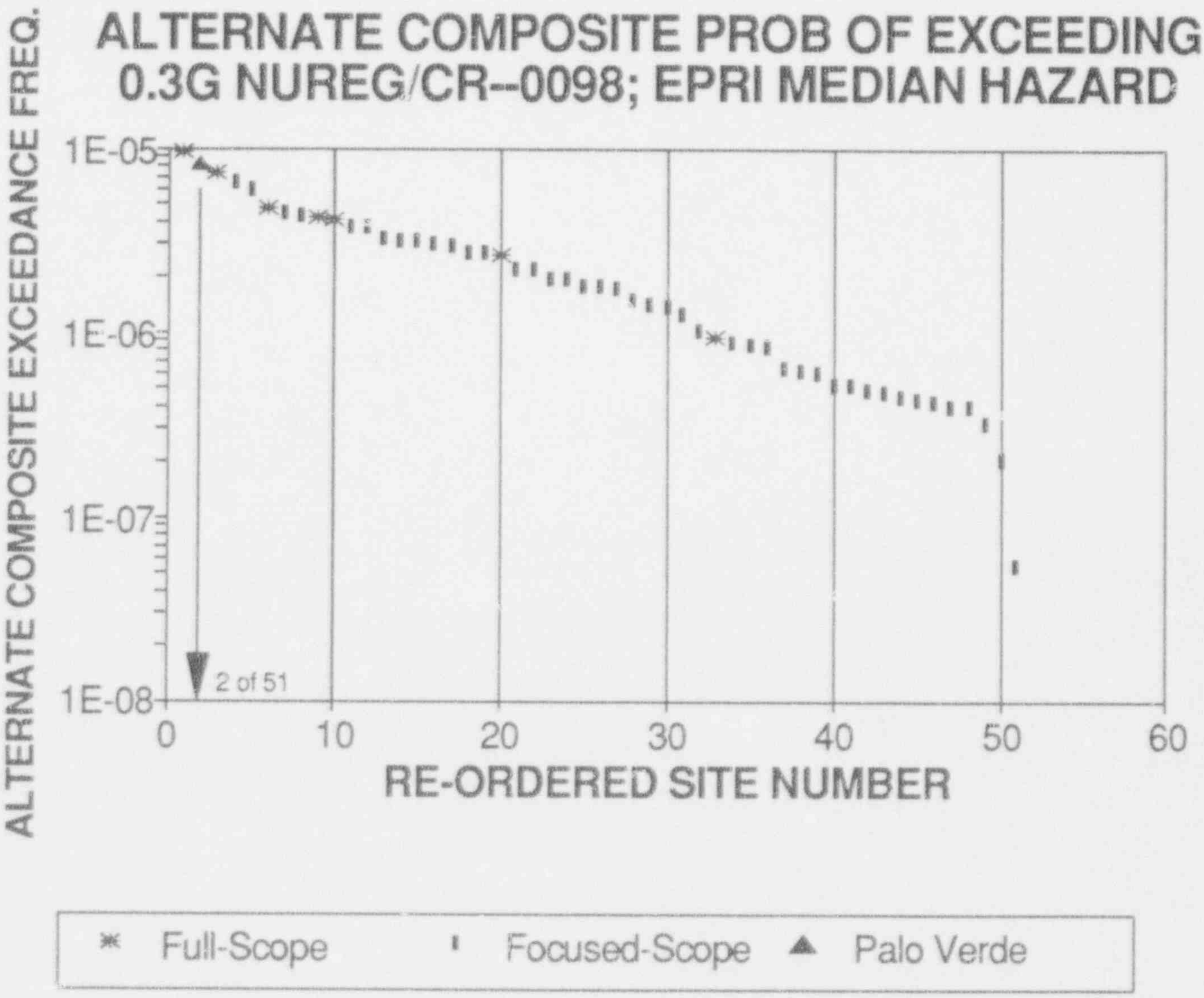


Figure A-14. Comparison of the alternate-composite median probability of exceeding the NUREG/CR-0098 median, 5%-damped spectrum anchored to 0.3g: comparison of results for the the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

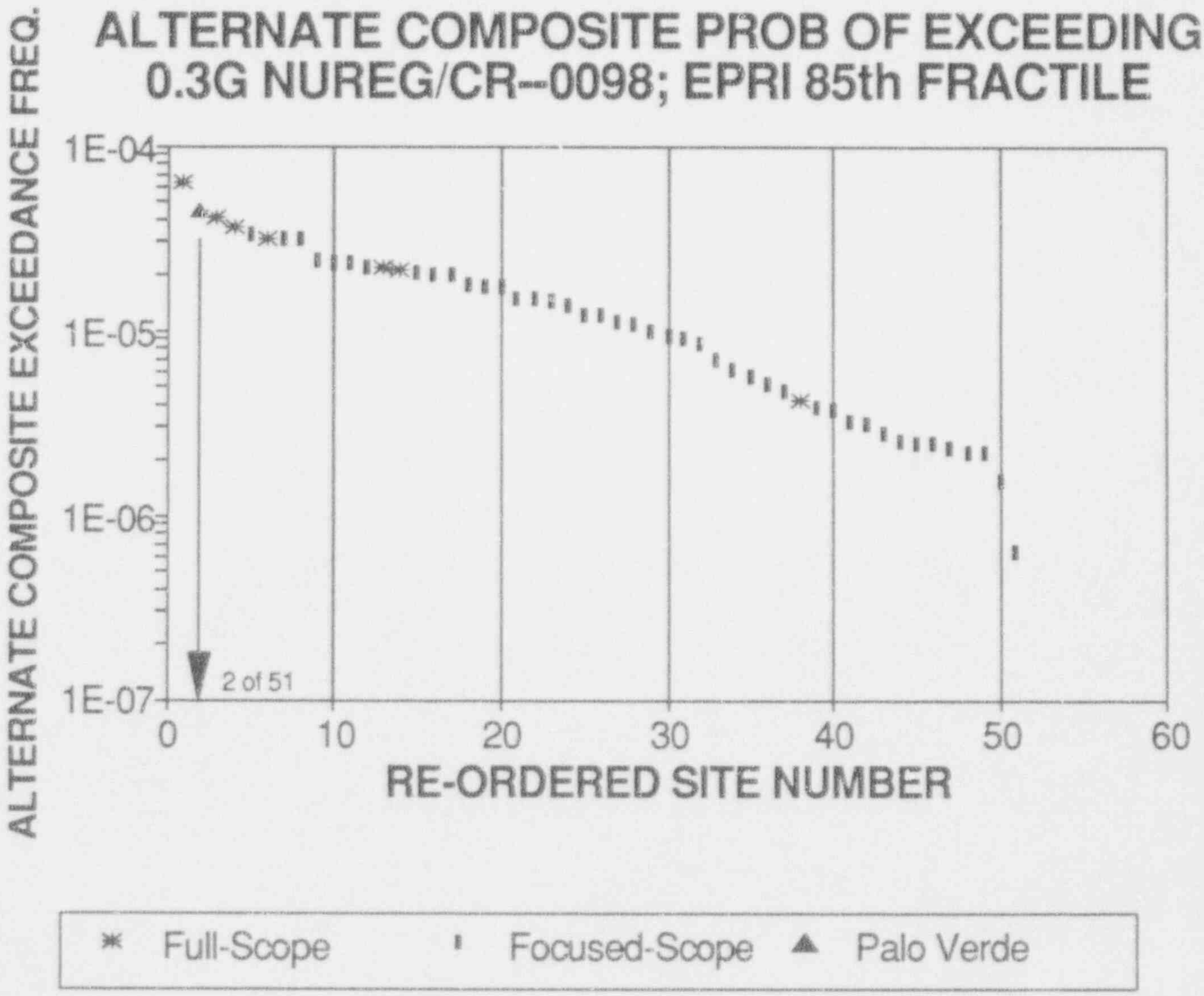


Figure A-15. Comparison of the alternate-composite 85th-fractile probability of exceeding the NUREG/CR-0098 median, 5%-damped spectrum anchored to 0.3g: comparison of results for the the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

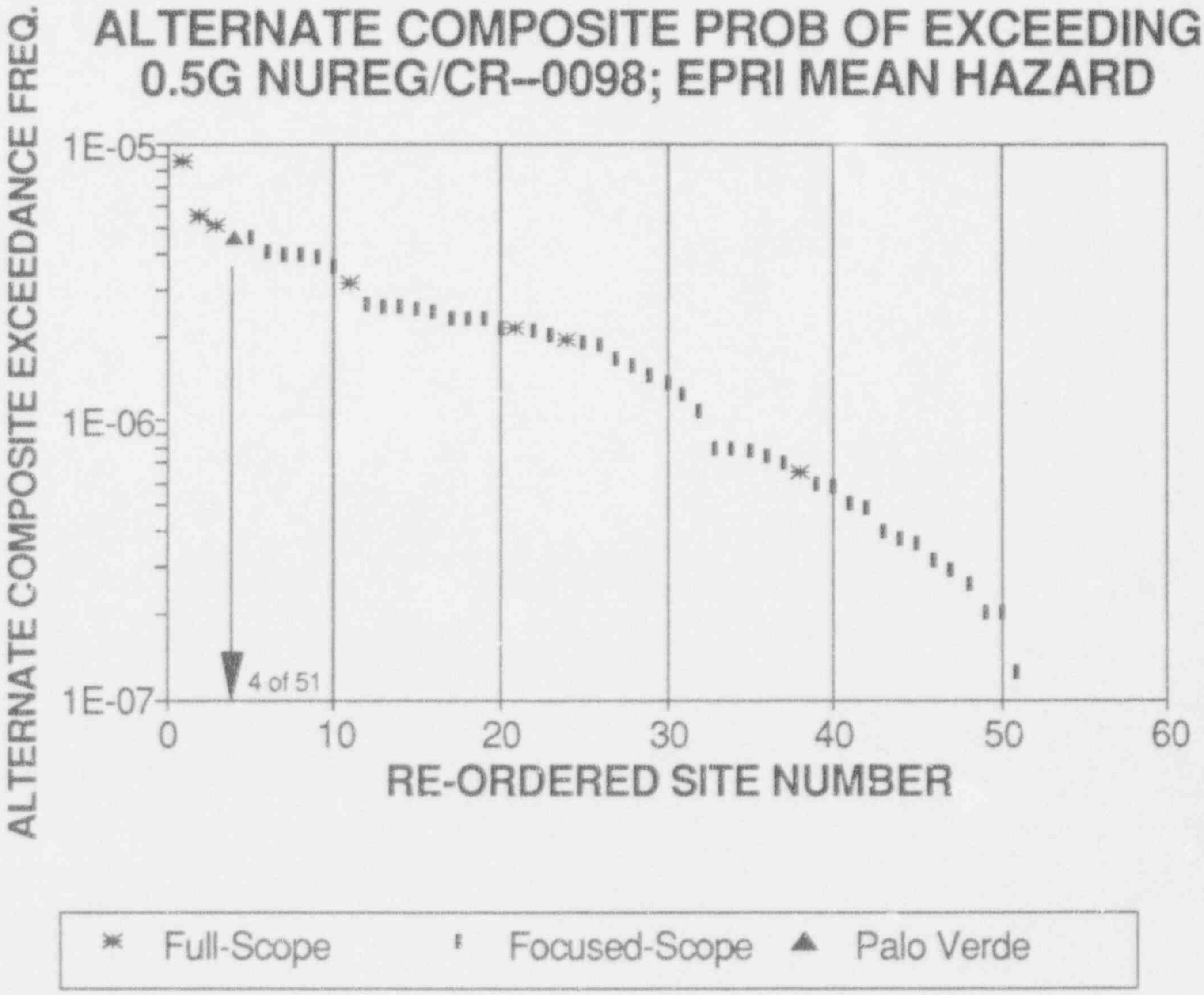


Figure A-16. Comparison of the alternate-composite mean probability of exceeding the NUREG/CR-0098 median, 5%-damped spectrum anchored to 0.5g: comparison of results for the the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

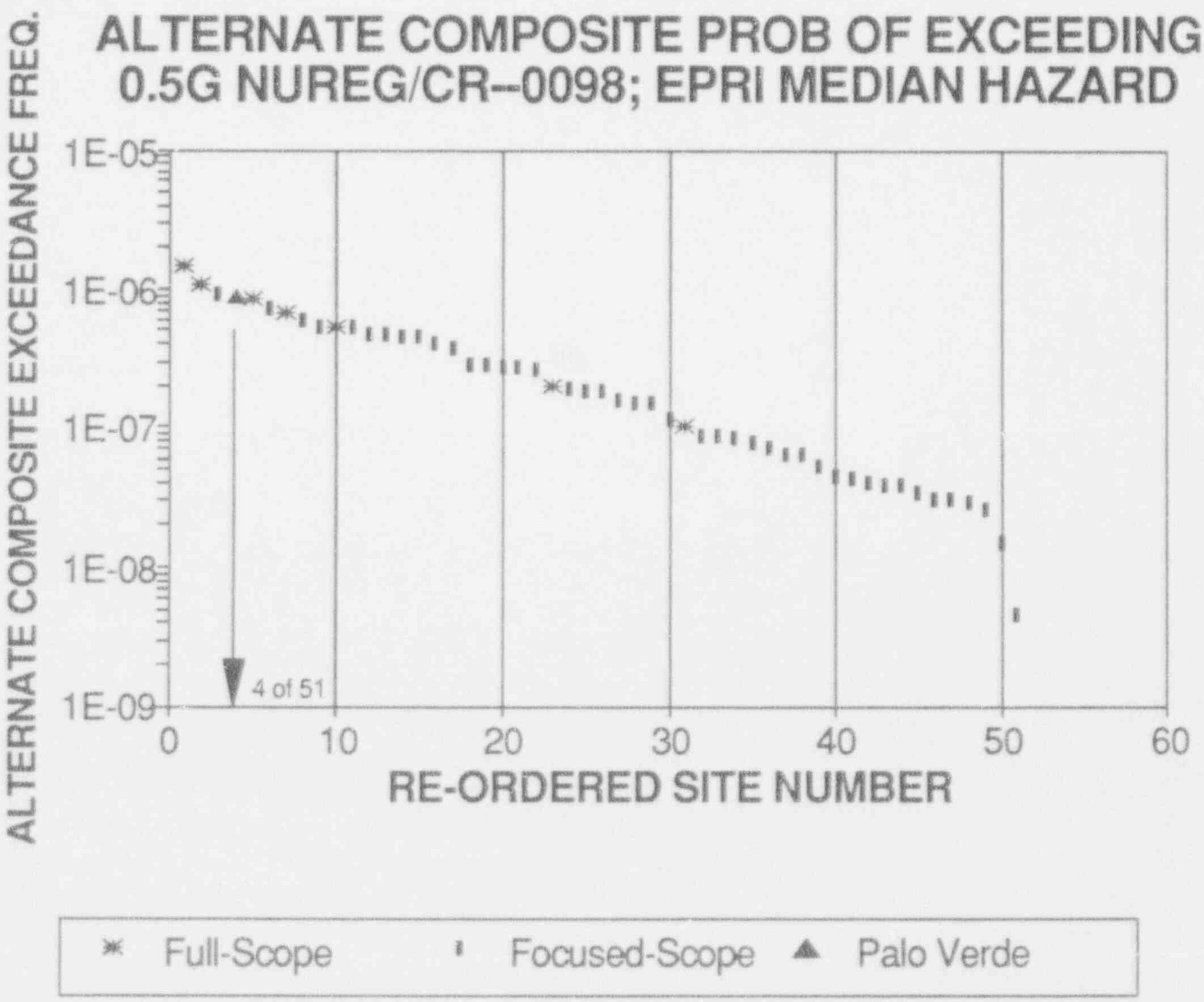


Figure A-17. Comparison of the alternate-composite median probability of exceeding the NUREG/CR-0098 median, 5%-damped spectrum anchored to 0.5g: comparison of results for the the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

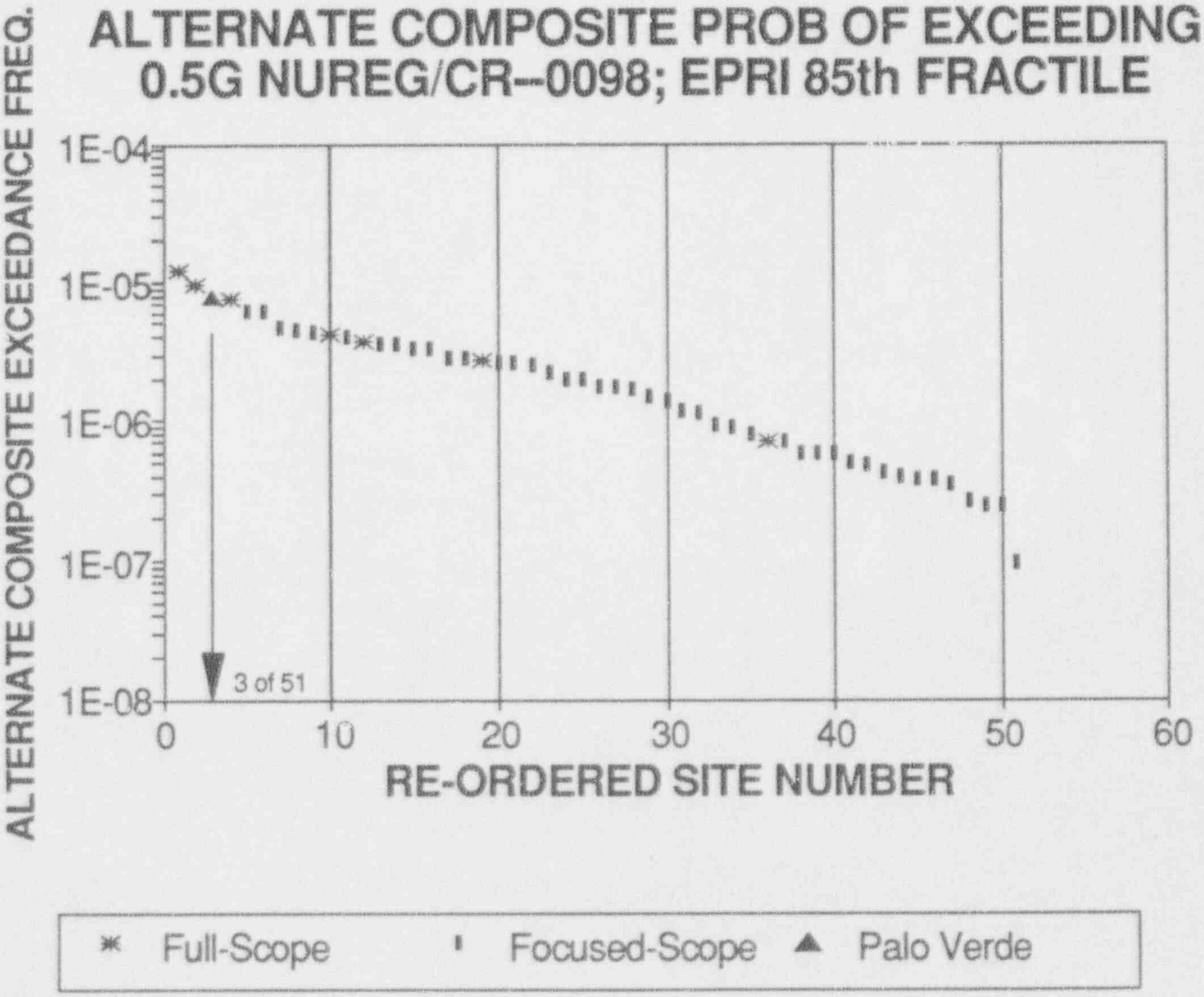


Figure A-18. Comparison of the alternate-composite 85th-fractile probability of exceeding the NUREG/CR-0098 median, 5%-damped spectrum anchored to 0.5g: comparison of results for the the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

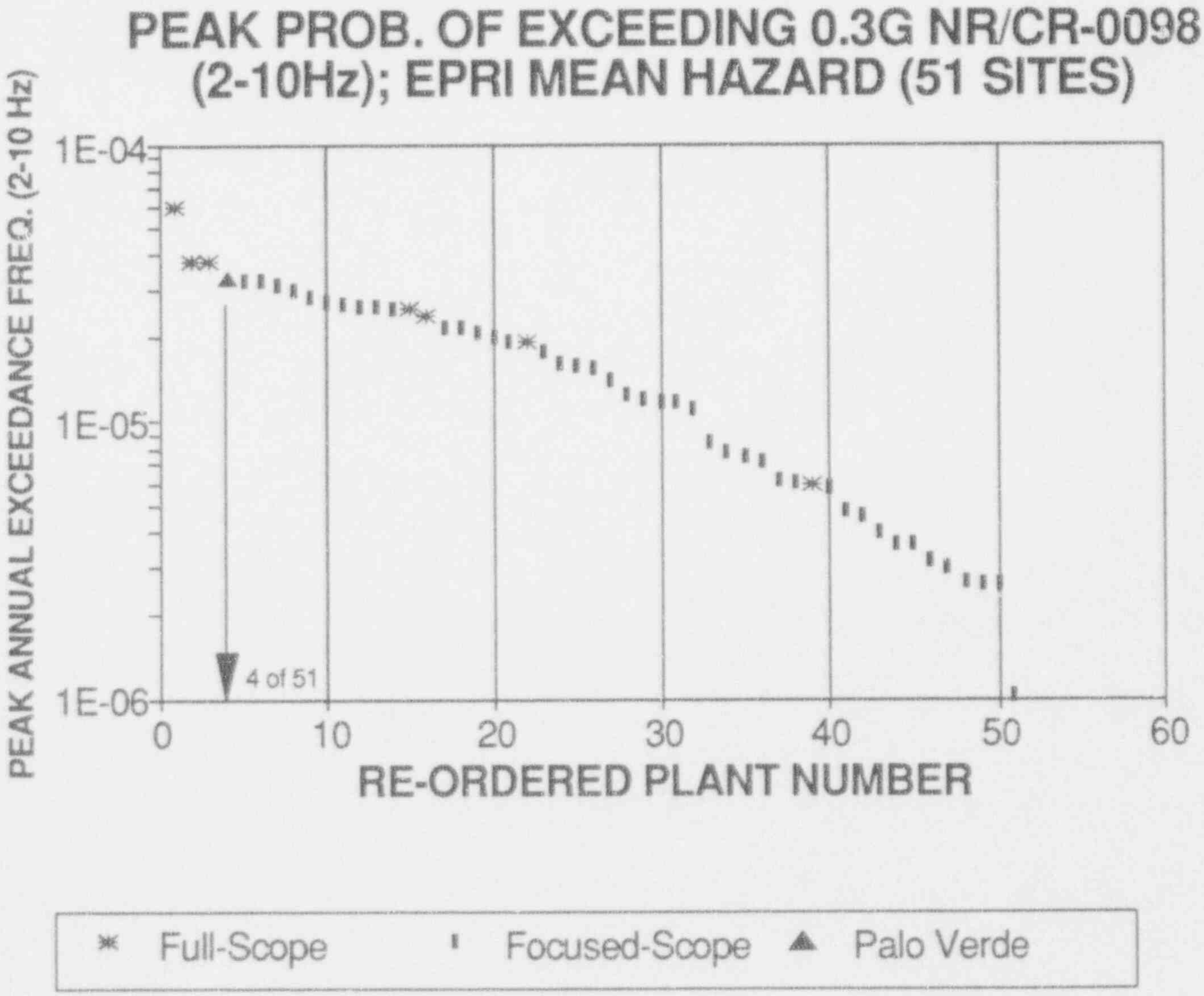


Figure A-19. Comparison of the peak (over the frequency range of 2 to 10 Hz) mean probability of exceeding the NUREG/CR-0098 median, 5%-damped spectrum anchored to 0.3g: comparison of results for the the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

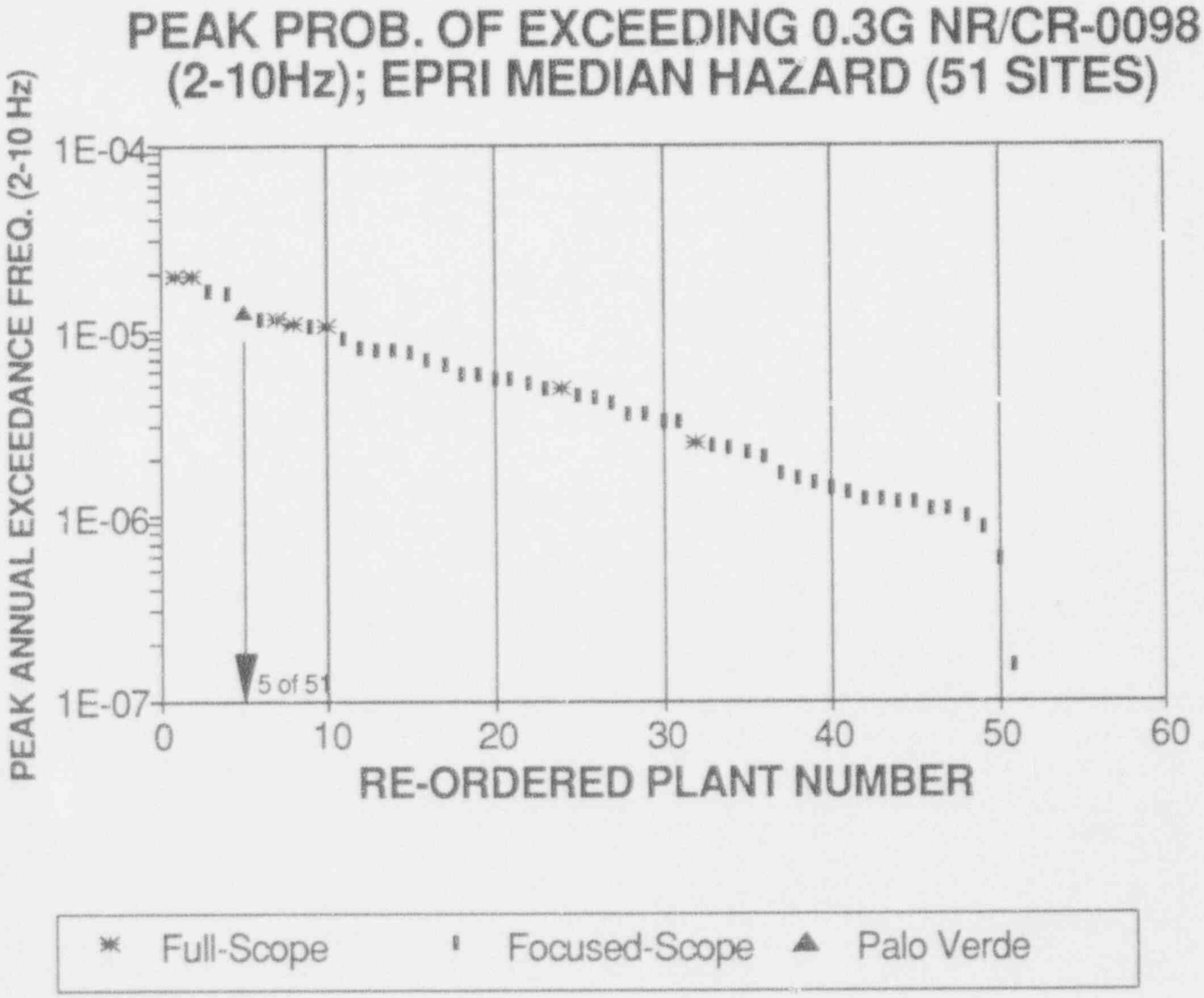


Figure A-20. Comparison of the peak (over the frequency range of 2 to 10 Hz) median probability of exceeding the NUREG/CR-0098 median, 5%-damped spectrum anchored to 0.3g: comparison of results for the the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

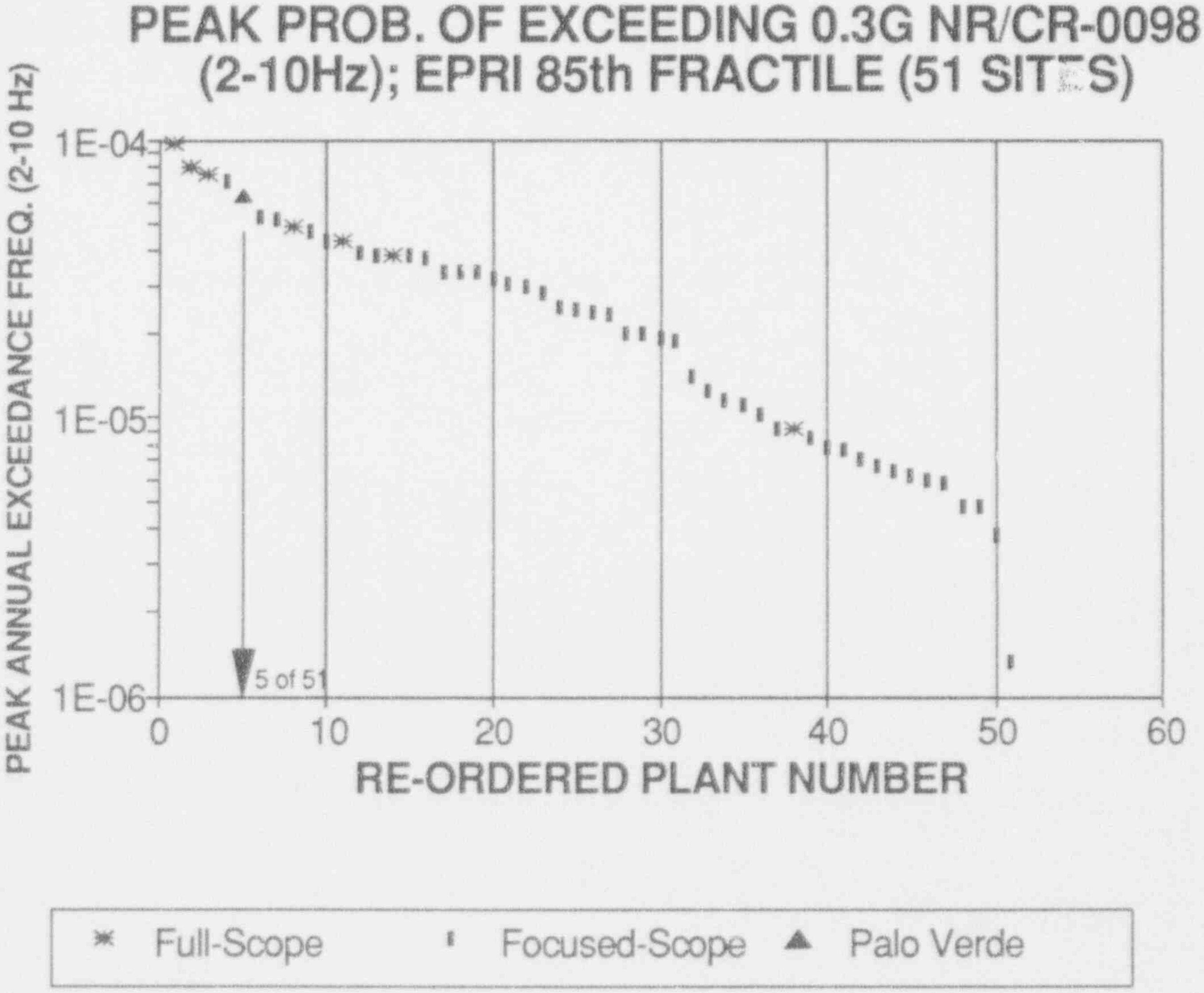


Figure A-21. Comparison of the peak (over the frequency range of 2 to 10 Hz) 85th-fractile probability of exceeding the NUREG/CR-0098 median, 5%-damped spectrum anchored to 0.3g: comparison of results for the the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

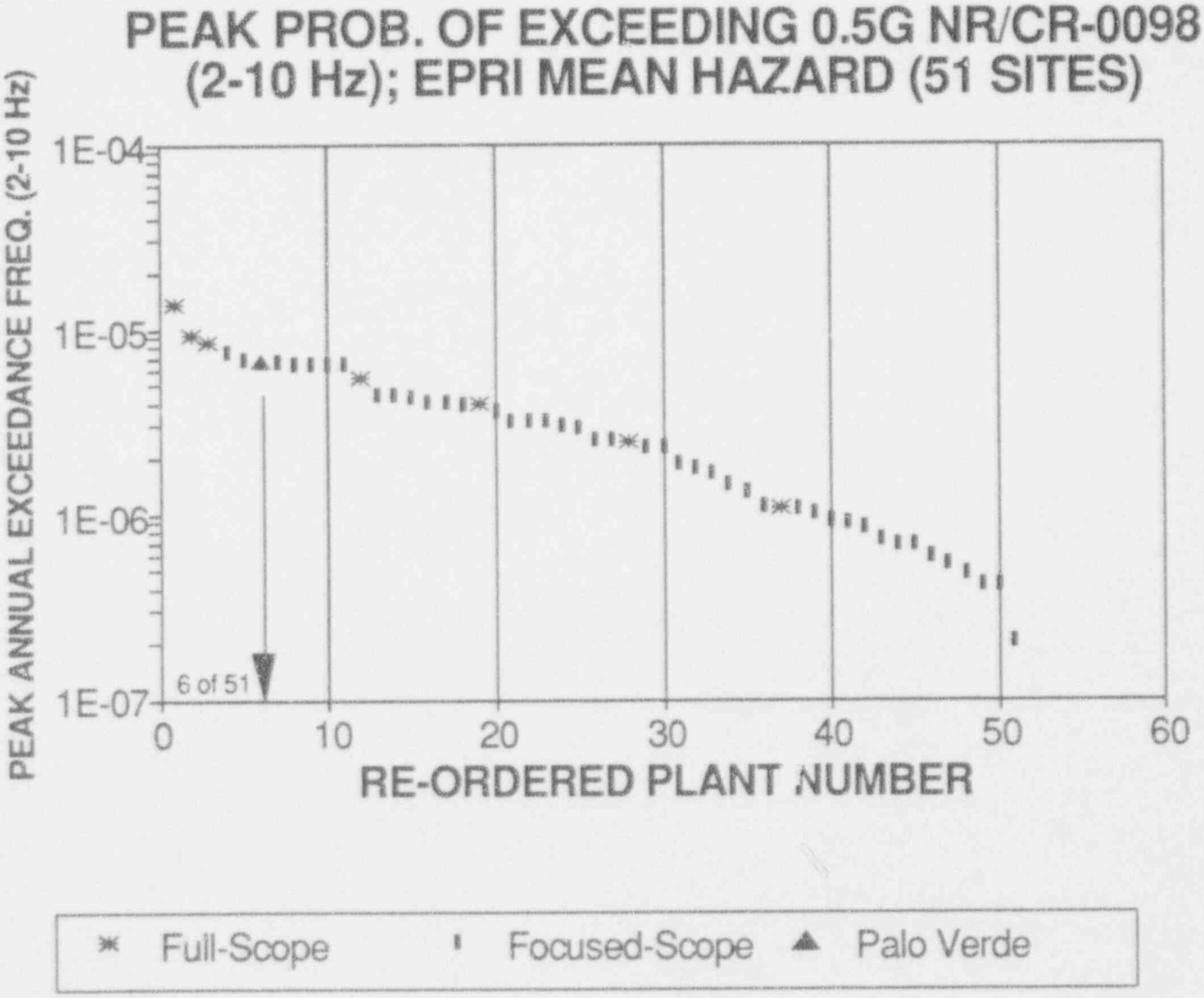


Figure A-22. Comparison of the peak (over the frequency range of 2 to 10 Hz) mean probability of exceeding the NUREG/CR-0098 median, 5%-damped spectrum anchored to 0.5g: comparison of results for the the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

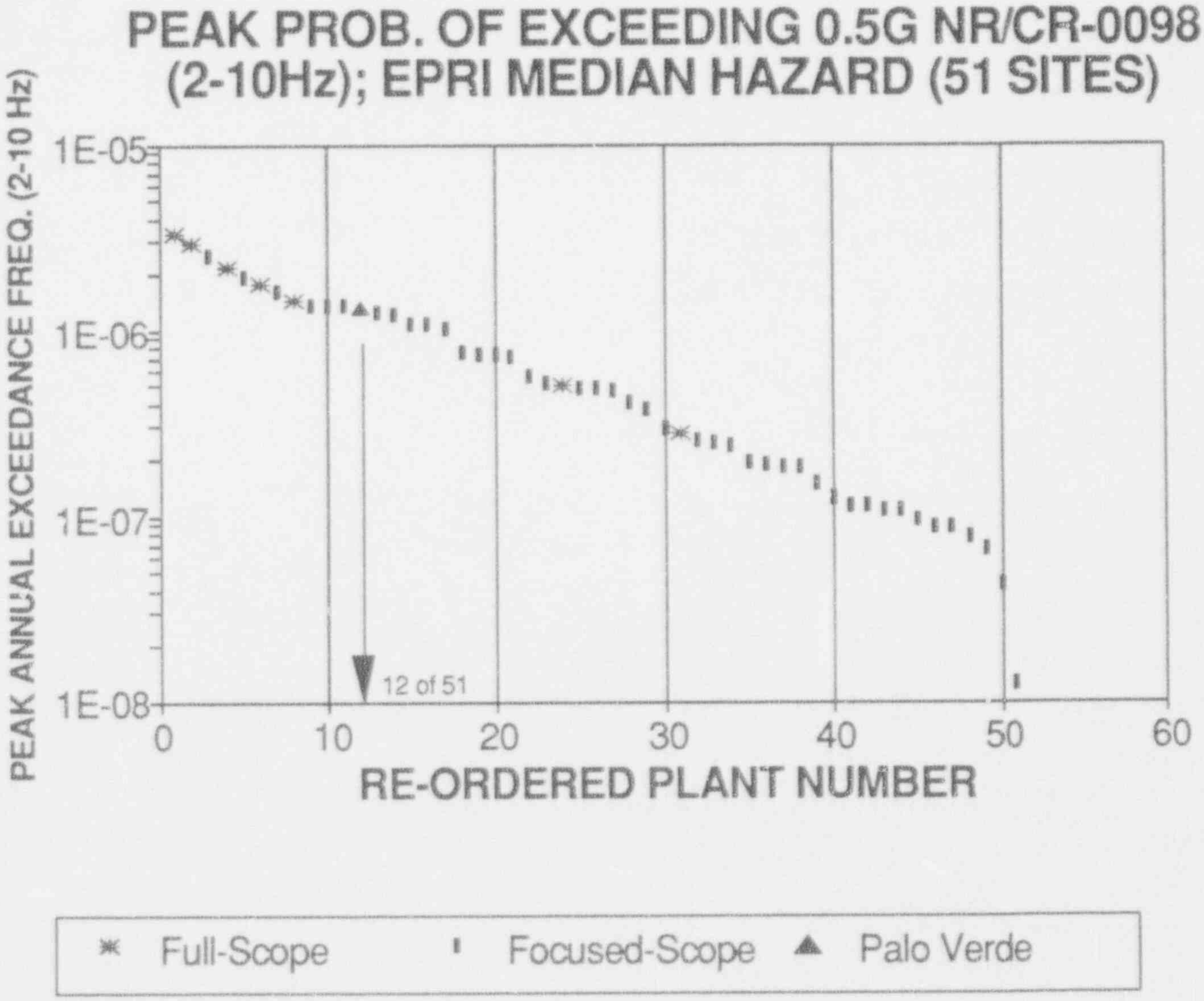


Figure A-23. Comparison of the peak (over the frequency range of 2 to 10 Hz) median probability of exceeding the NUREG/CR-0098 median, 5%-damped spectrum anchored to 0.5g: comparison of results for the the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

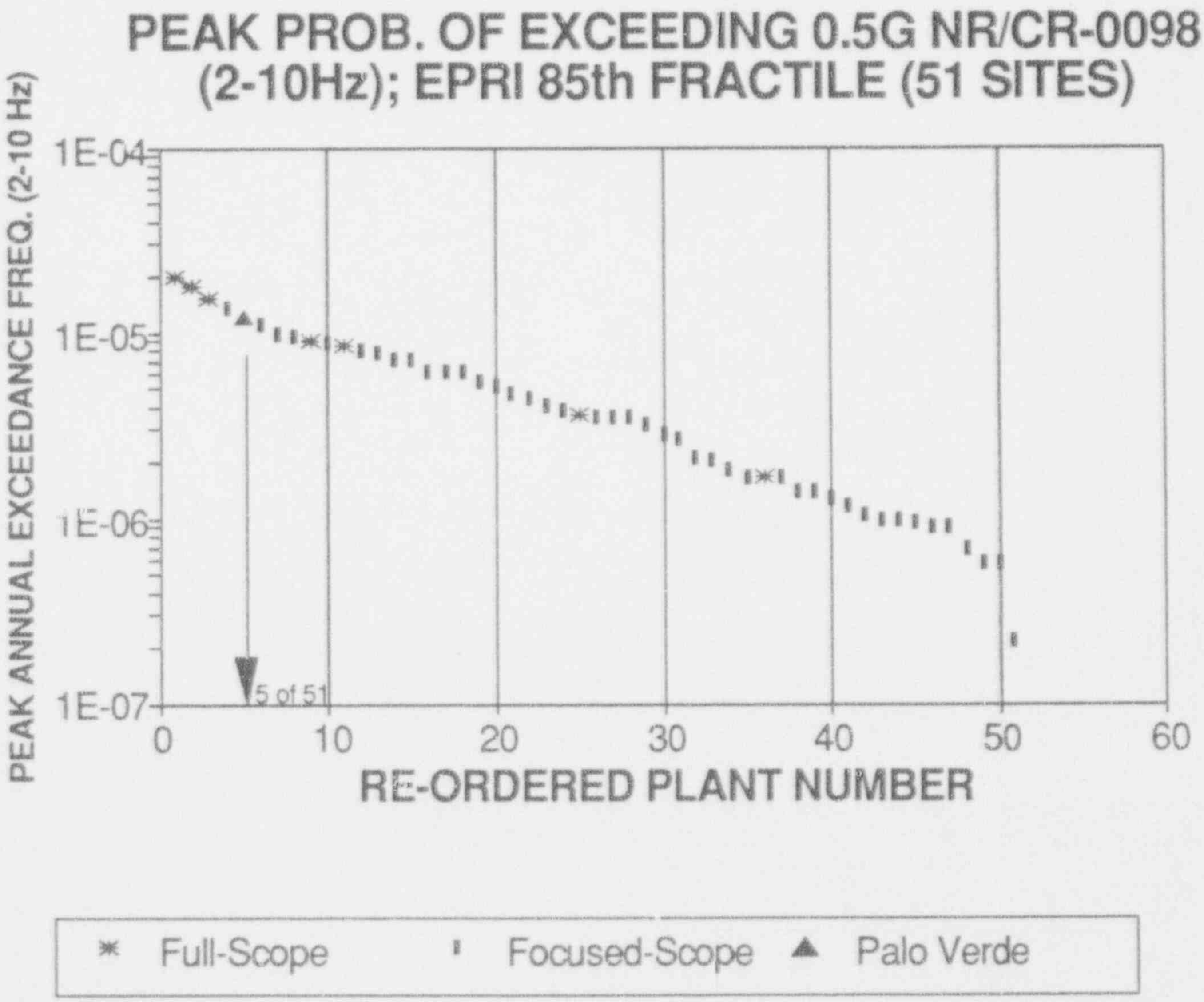


Figure A-24. Comparison of the peak (over the frequency range of 2 to 10 Hz) 85th-fractile probability of exceeding the NUREG/CR-0098 median, 5%-damped spectrum anchored to 0.5g: comparison of results for the the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

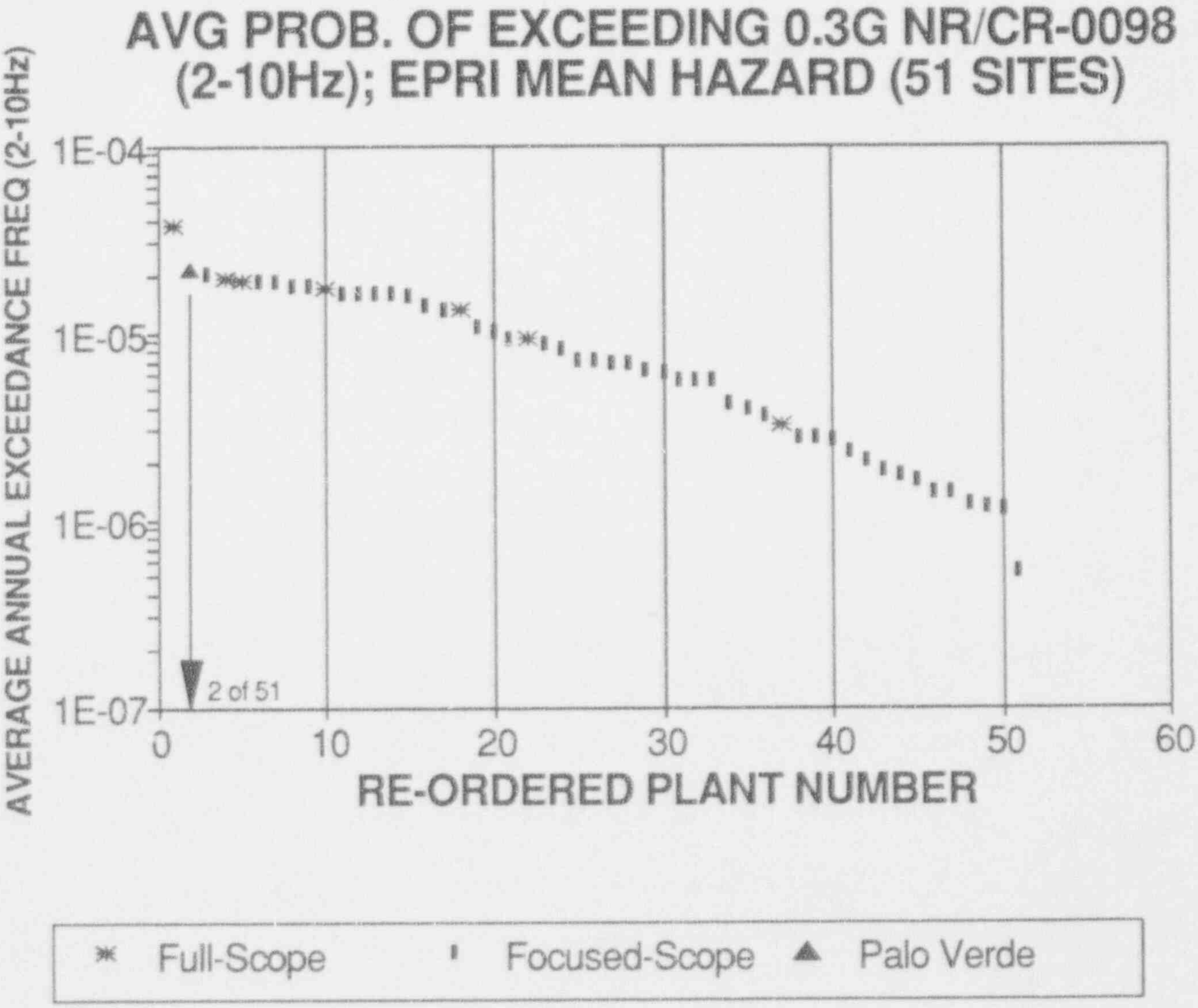


Figure A-25. Comparison of the average (over the frequency range of 2 to 10 Hz) mean probability of exceeding the NUREG/CR-0098 median, 5%-damped spectrum anchored to 0.3g: comparison of results for the the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

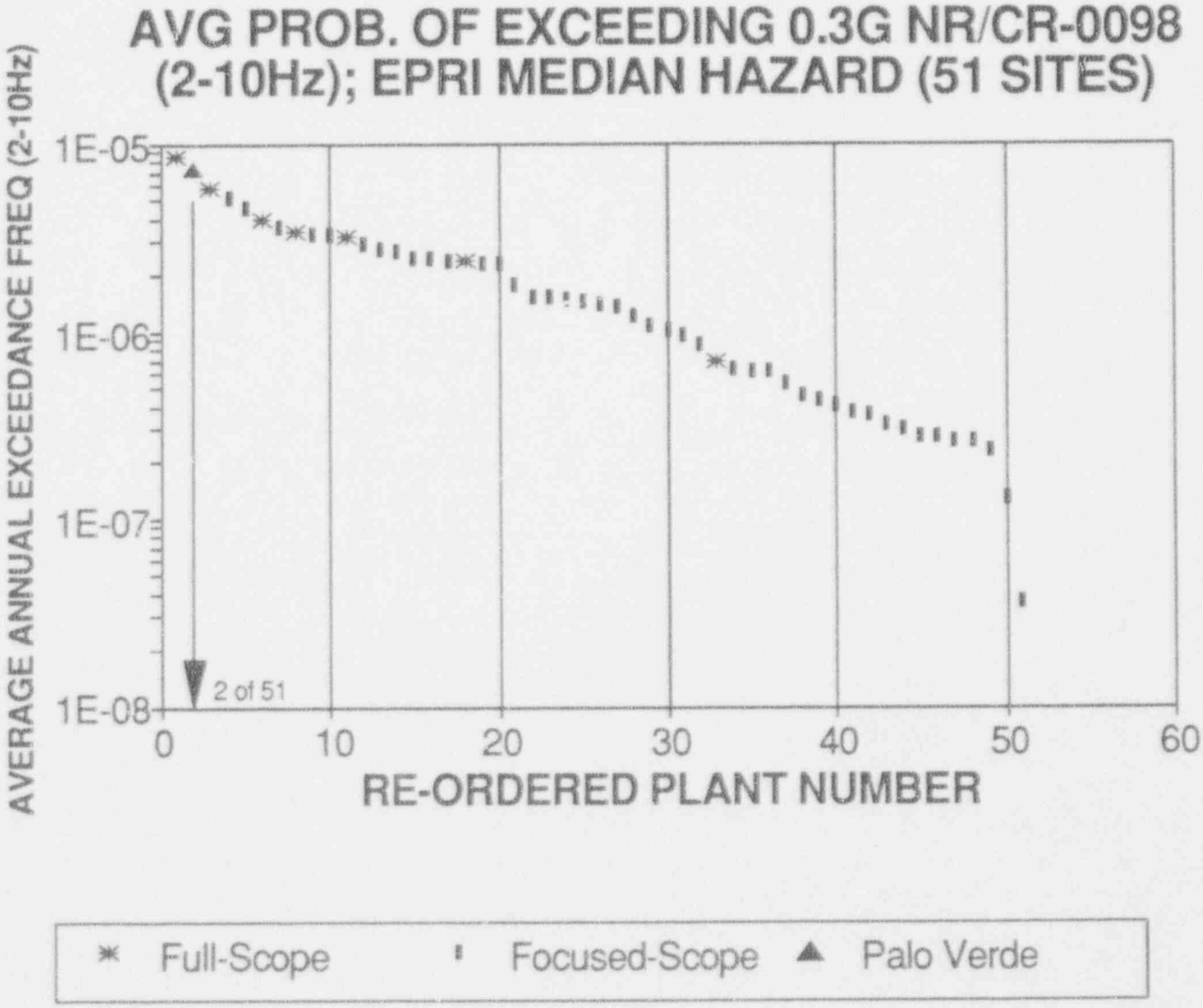


Figure A-26. Comparison of the average (over the frequency range of 2 to 10 Hz) median probability of exceeding the NUREG/CR-0098 median, 5%-damped spectrum anchored to 0.3g: comparison of results for the the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

1

IMAGE EVALUATION TEST TARGET (MT-3)

150mm

6″

1

IMAGE EVALUATION TEST TARGET (MT-3)

1.0 2.8 2.5
3.2 2.2
3.6
4.0 2.0
1.1
1.8
1.25 1.4 1.6

150mm

6"

1

IMAGE EVALUATION TEST TARGET (MT-3)

150mm

6"

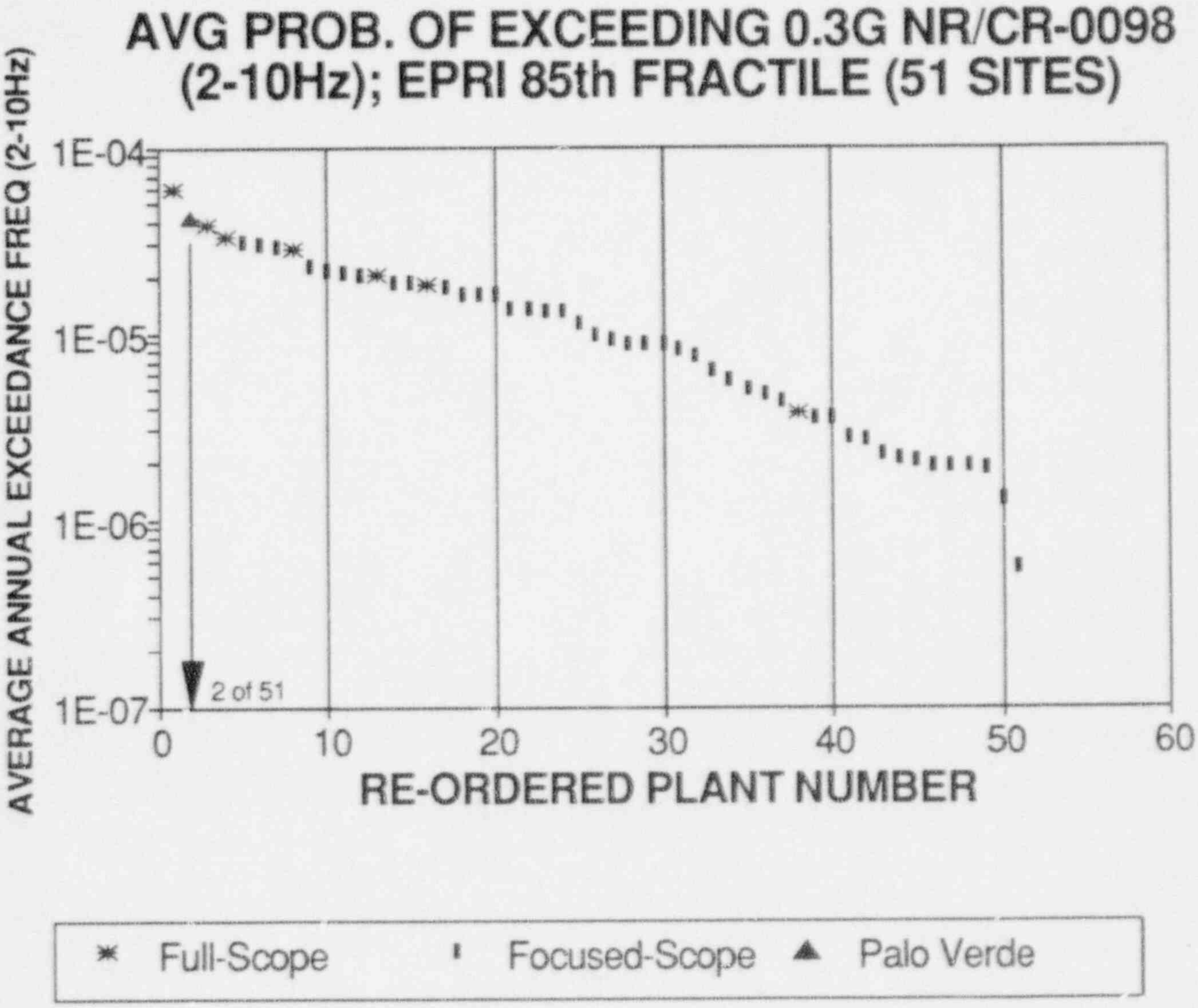


Figure A-27. Comparison of the average (over the frequency range of 2 to 10 H.` 85th-fractile probability of exceeding the NUREG/CR-0098 median, 5%-damped spectrum anchored to 0.3g: comparison of results for the the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g pla:.ts in the central and eastern U.S.

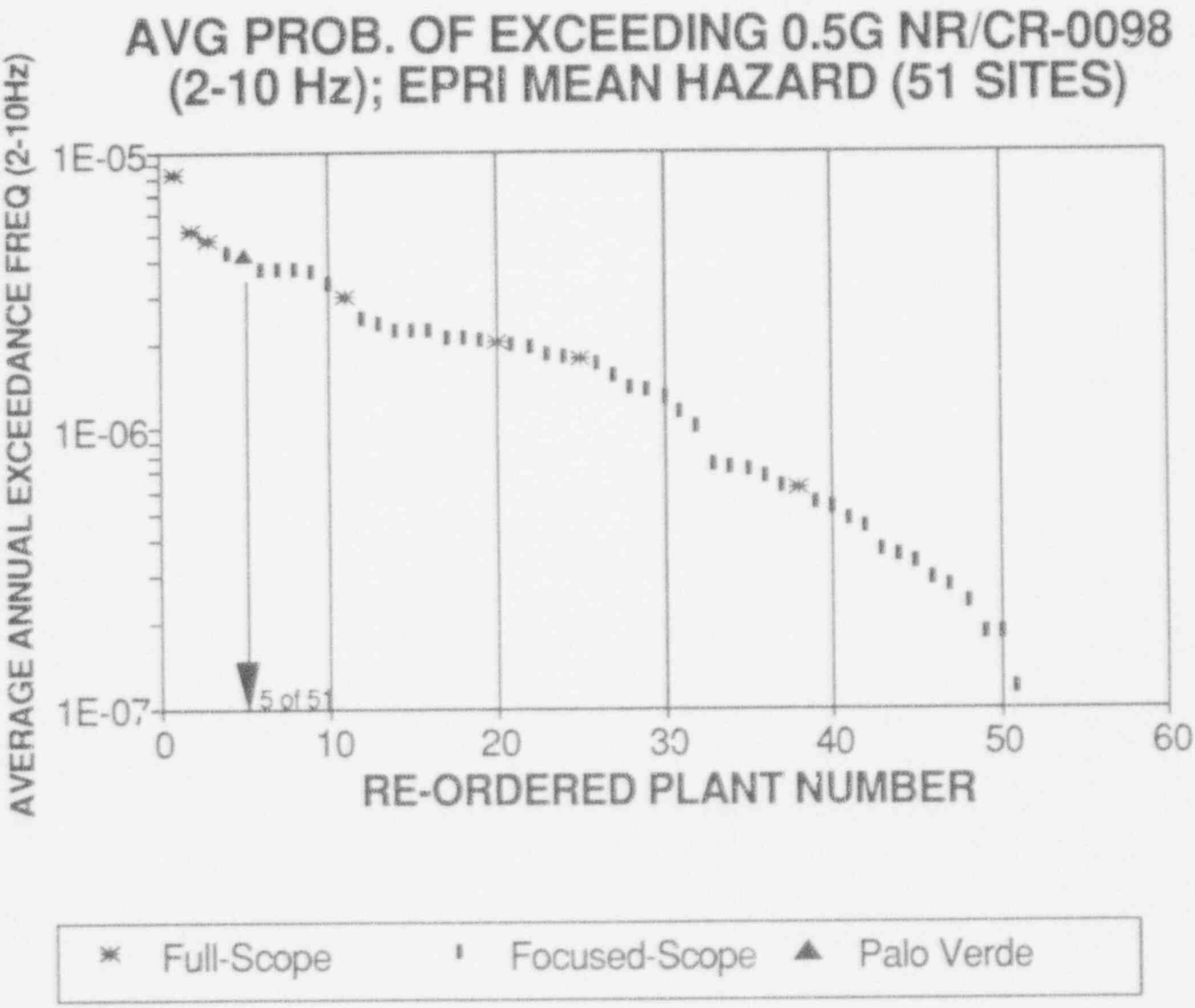


Figure A-28. Comparison of the average (over the frequency range of 2 to 10 Hz) mean probability of exceeding the NUREG/CR-0098 median, 5%-damped spectrum anchored to 0.5g: comparison of results for the the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

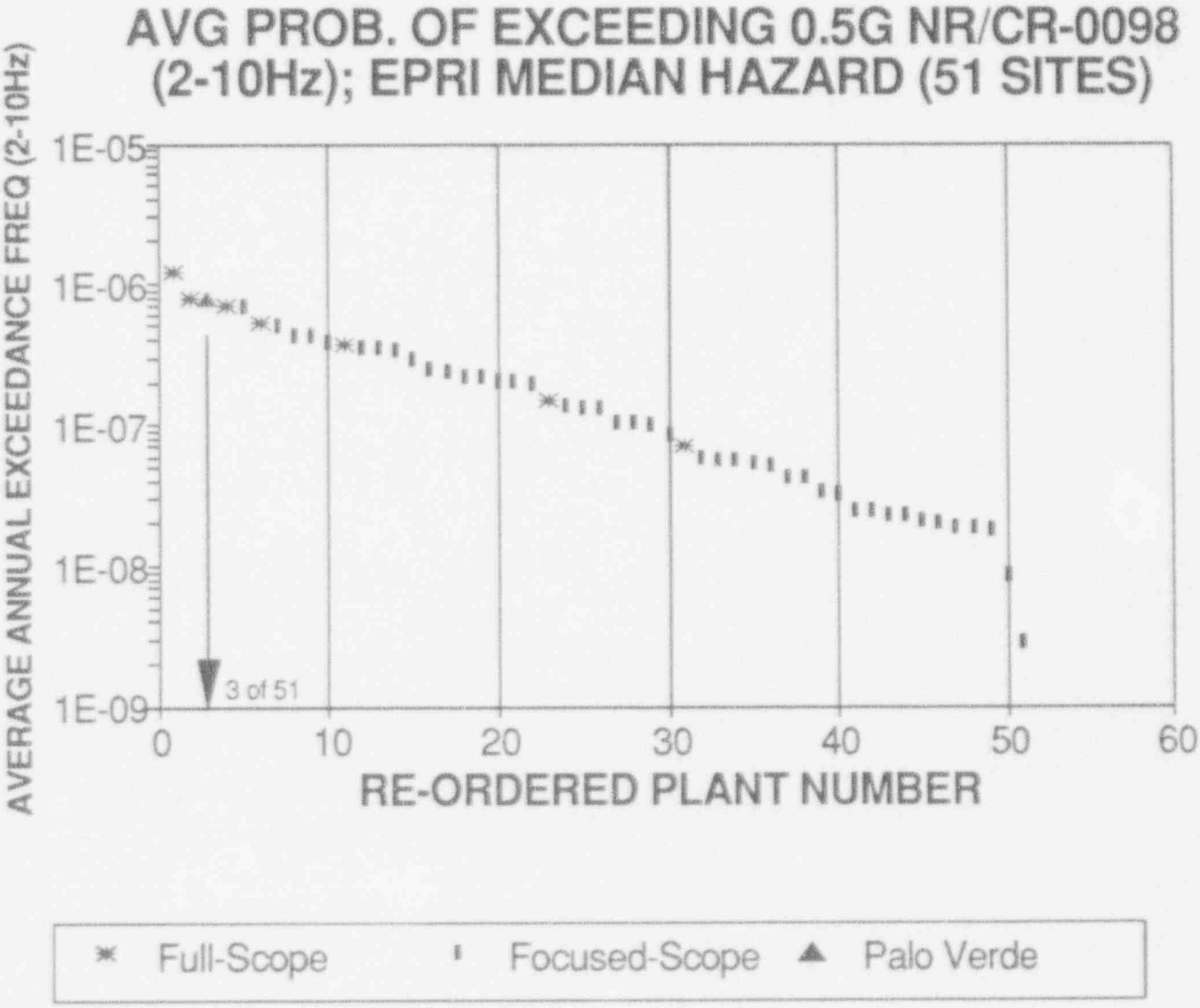


Figure A-29. Comparison of the average (over the frequency range of 2 to 10 Hz) median probability of exceeding the NUREG/CR-0098 median, 5%-damped spectrum anchored to 0.5g: comparison of results for the the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

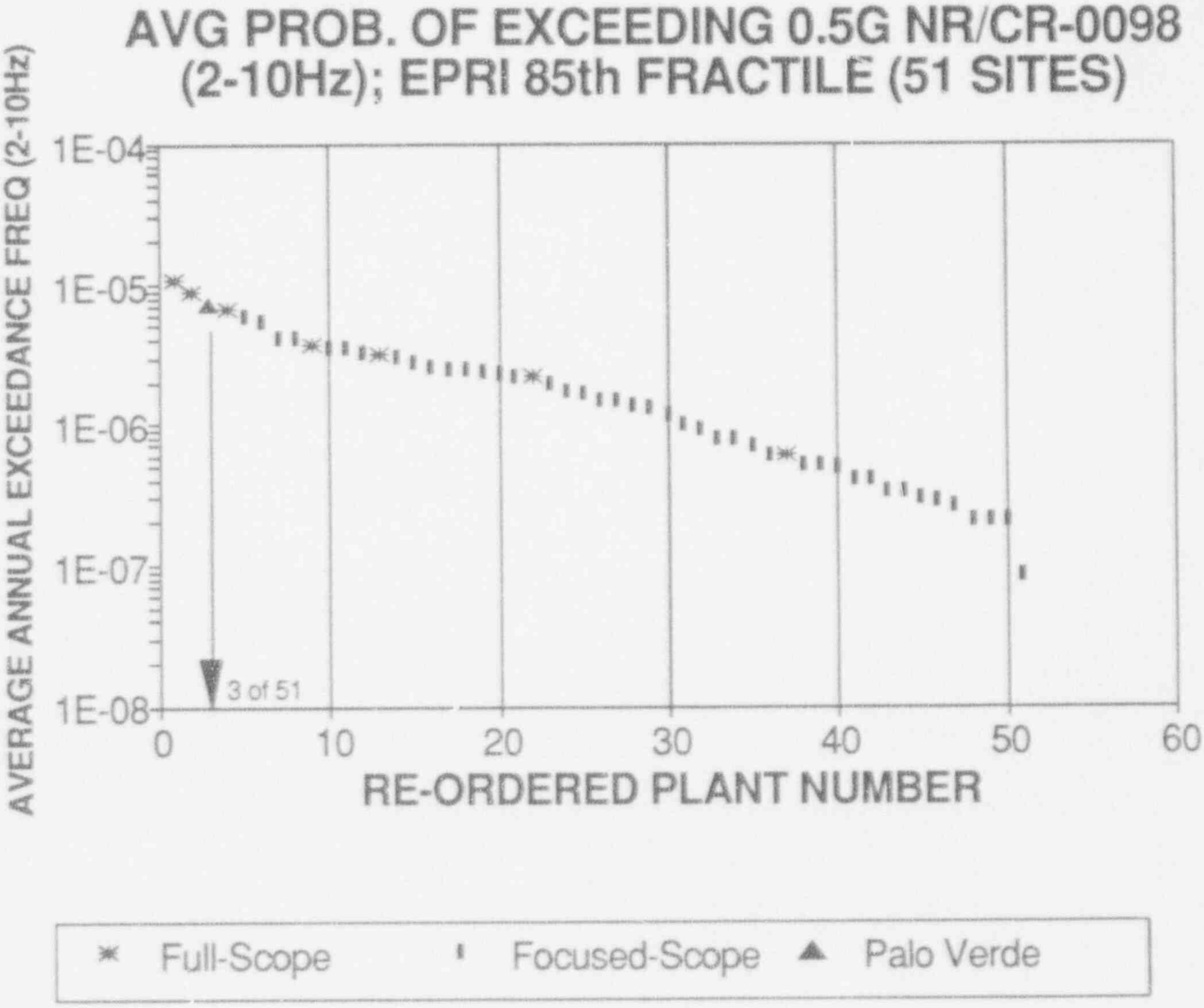


Figure A-30. Comparison of the average (over the frequency range of 2 to 10 Hz) 85th-fractile probability of exceeding the NUREG/CR-0098 median, 5%-damped spectrum anchored to 0.5g: comparison of results for the the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

Appendix B

COMPARISONS OF PROBABILITIES OF EXCEEDING DESIGN-BASIS SPECTRA

This appendix presents probabilities of exceeding plant seismic design-basis spectra. Design-basis exceedance-probability results for PGA and for spectral frequencies are provided for the Palo Verde site and for 50 nuclear power plant locations in the central and eastern United States. The exceedance probabilities are determined as outlined in Section 4, and are computed for reference spectra defined by plant-specific seismic design (SSE) levels. Scalar measures of exceedance probabilities have been derived from the exceedance-probability spectra; the scalar measures include composite probability of exceedance, alternate-composite probability of exceedance, peak exceedance probability over the vibrational-frequency range of 2.0 to 10.0 Hz, and exceedance probability averaged over the same frequency range (see Section 4 for more detailed defininitions of these measures). In all cases (for exceedance-probability spectra or for derived scalar measures) comparisons are provided for the mean, median, and 85th-fractile hazards.

Hazard results for the 50 central and eastern U.S. sites are based on the EPRI methodology. The 50 sites are comprised of the 0.3g full-scope and focused-scope plants for which EPRI hazard results have been obtained; seven of these plants are full-scope plants, and the remaining 43 are focused-scope plants.

Figures B-1 to B-3 present, respectively, spectra of the mean, median, and 85th-fractile probabilities of exceeding plant design-basis input.

[In these spectral plots, results of probabilities of exceeding design-basis PGA are indicated by horizontal lines from 65.0 to 100.0 Hz. Consistent with results produced from the seismic hazard investigation for PVNGS and for other plants, spectra have not been computed nor plotted over the frequency range of 25 to 65 Hz. Because design spectra vary from plant to plant, estimates of how the exceedance-probability spectrum varies over this frequency range are not readily ascertainable from a general simplified procedure.]

Figures B-4 to B-6 present plots of ordered composite probability of exceedance. Here, each ordered plot presents a comparison of scalar measures corresponding to the respective

comparisons of exceedance probability spectra just described for Figures B–1 to B–3, where the design-basis spectrum is used as the basis for the transformation from ground motions to probabilities.

Figures B–7 to B–9 present plots of ordered alternate-composite probability of exceedance. Again, each ordered plot presents a comparison of scalar measures corresponding to the respective comparisons of exceedance probability spectra described for Figures B–1 to B–3.

Figures B–10 to B–12 and Figures B–13 to B–15 present, respectively, plots of ordered peak and average exceedance probability over the vibrational frequency range of 2 to 10 Hz. As before, the ordered plots correspond to each of the three comparisons noted earlier (i.e., for mean, median, 85th-fractile hazards).

The plots presented in this appendix support the comparisons and observations made in Section 5 of this report, and provide the basis for developing the plant rankings indicated in Table 5-2.

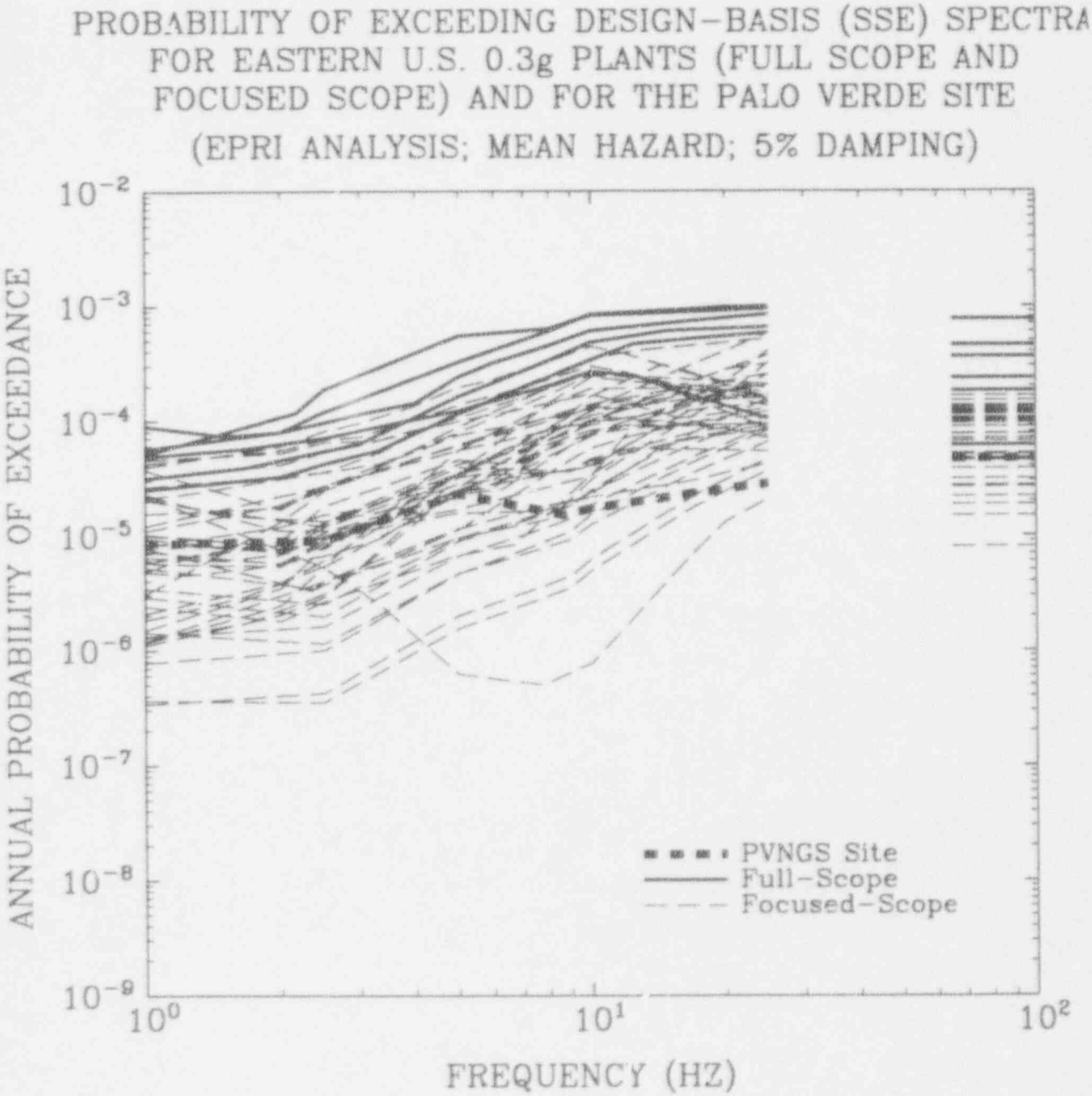


Figure B-1. Mean probabilities of exceeding the seismic design-basis spectrum: comparison of results for the the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

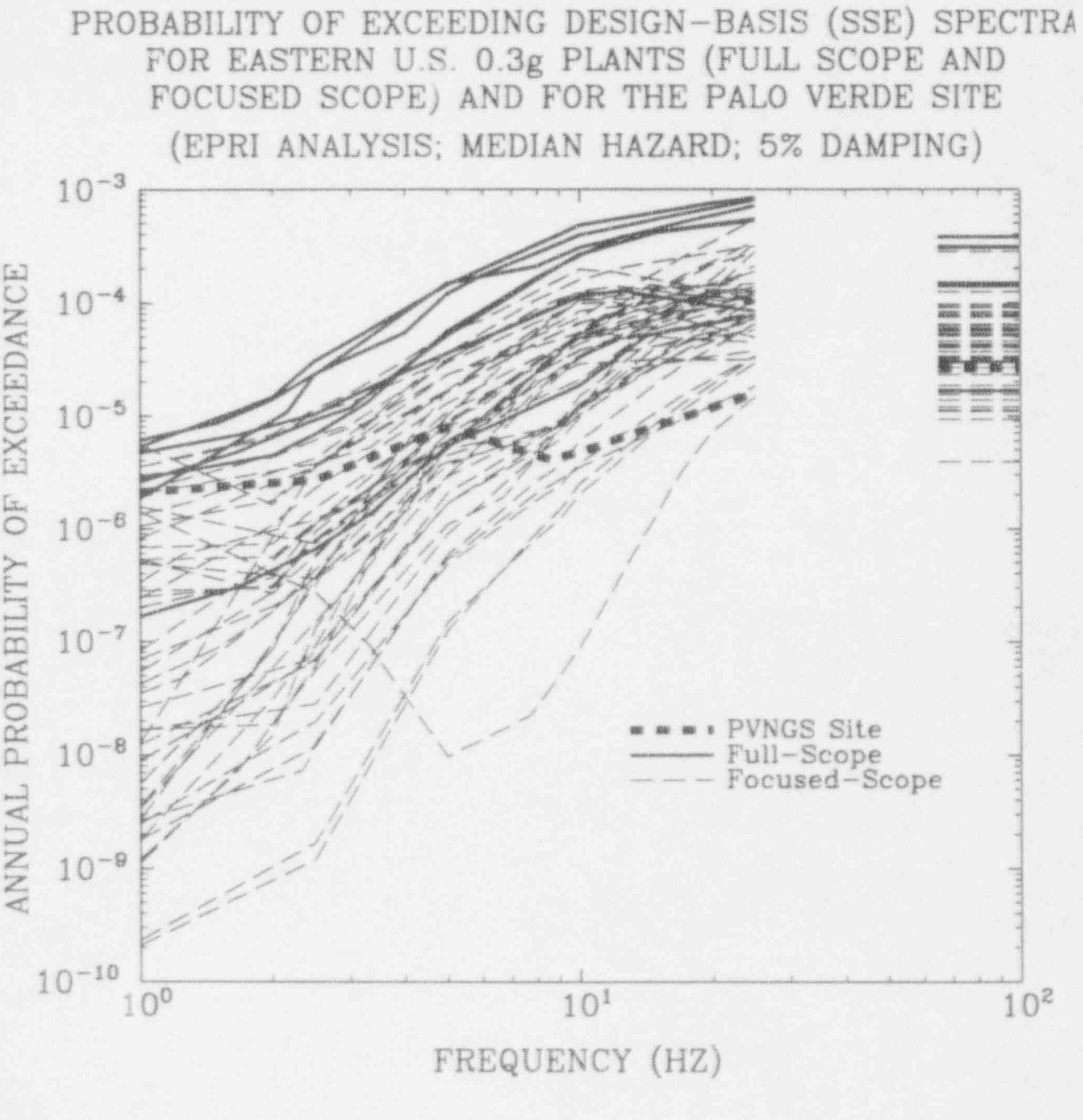


Figure B-2. Median probabilities of exceeding the seismic design-basis spectrum: comparison of results for the the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

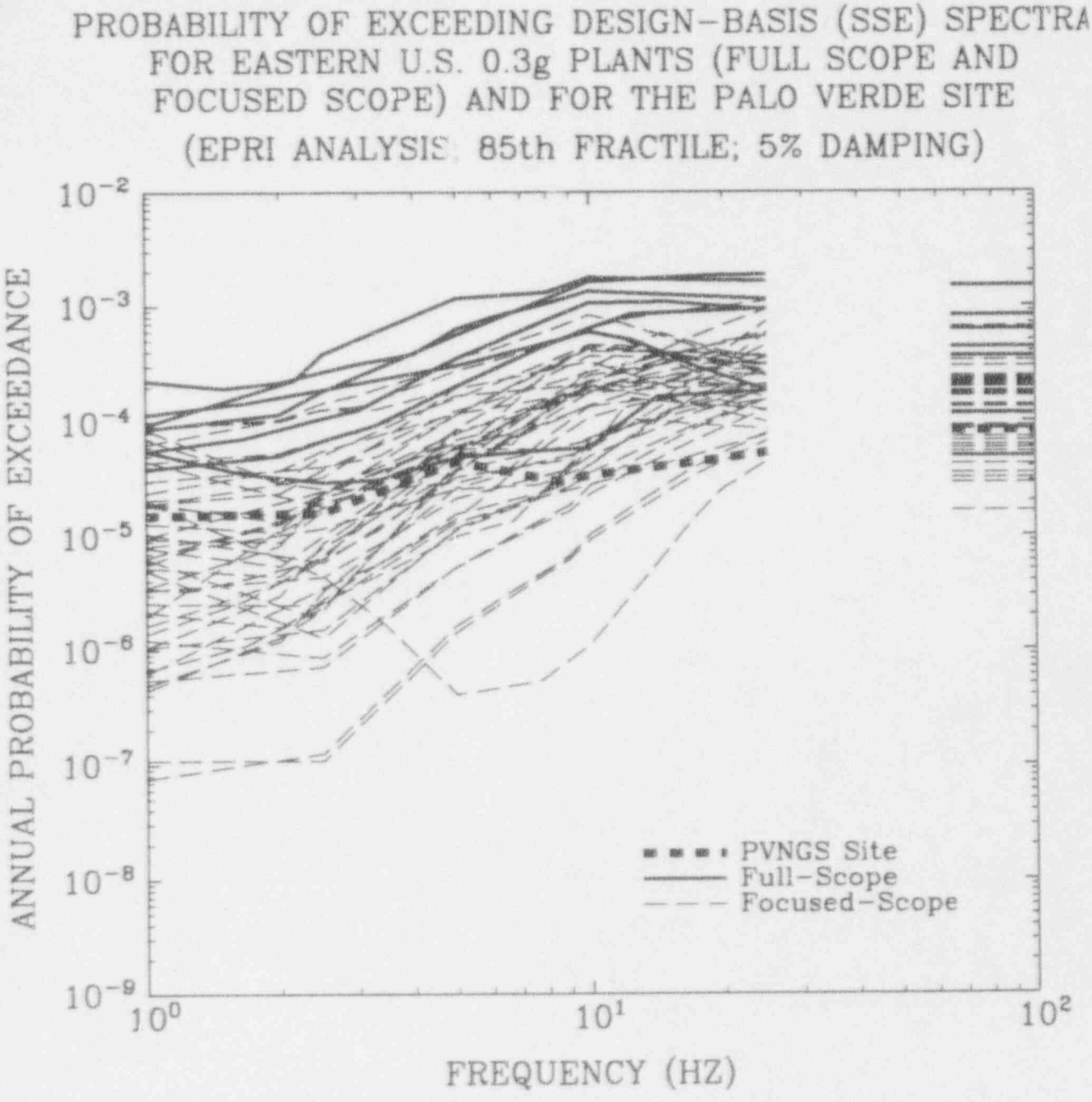


Figure B-3. 85th-fractile probabilities of exceeding the seismic design-basis spectrum: comparison of results for the the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

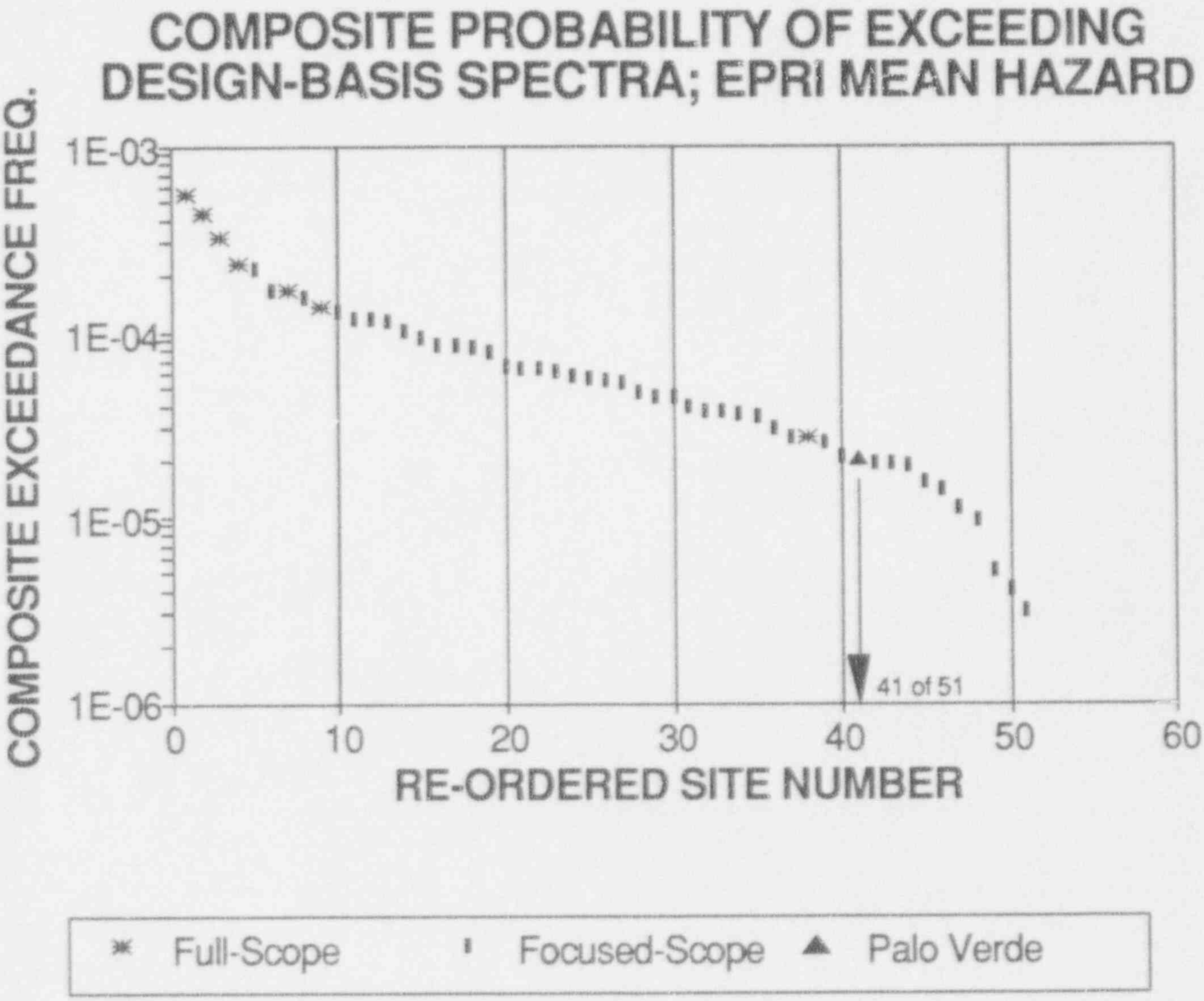


Figure B-4. Comparison of the composite mean probability of exceeding the seismic design-basis spectrum: comparison of results for the the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

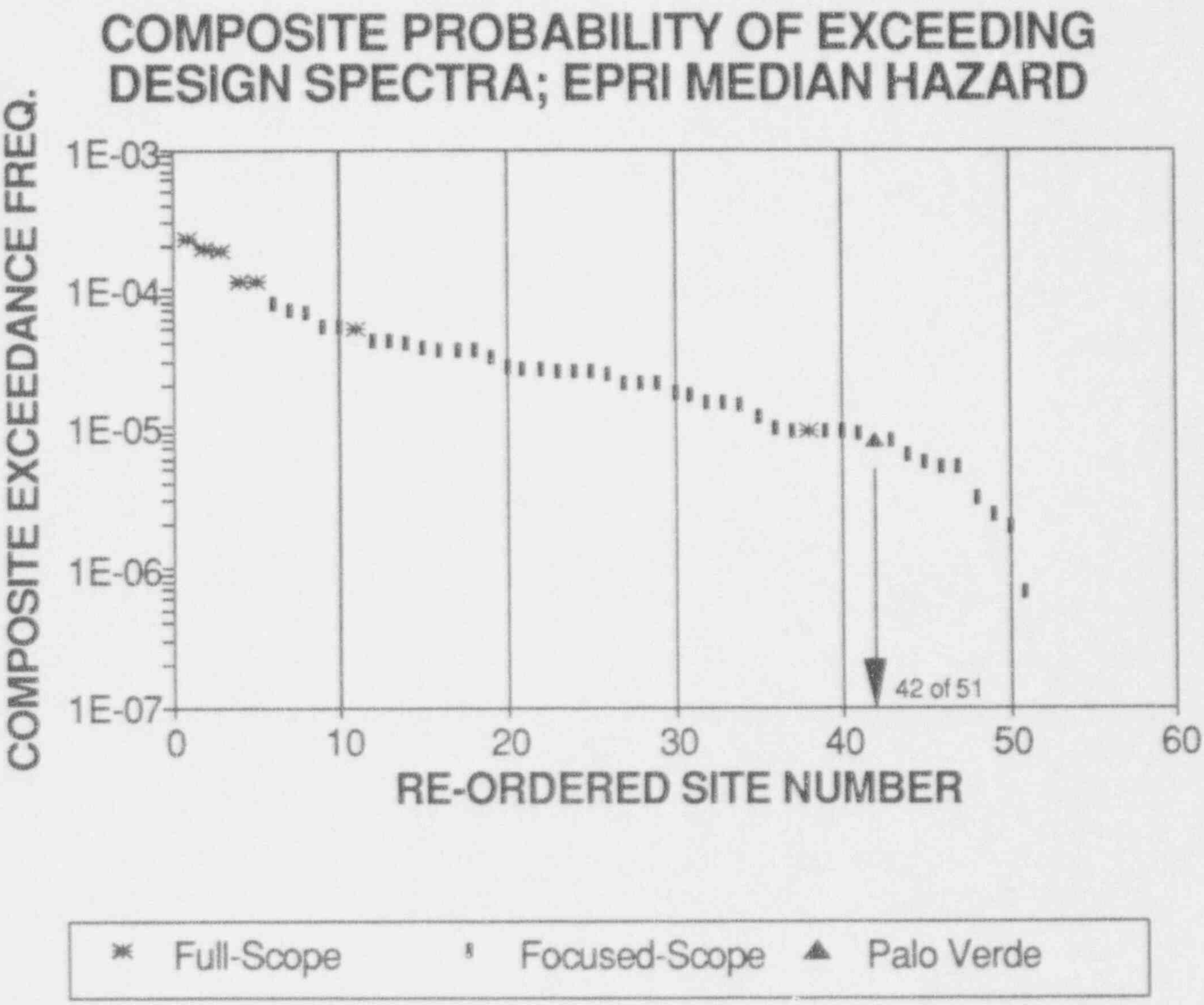


Figure B-5. Comparison of the composite median probability of exceeding the seismic design-basis spectrum: comparison of results for the the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

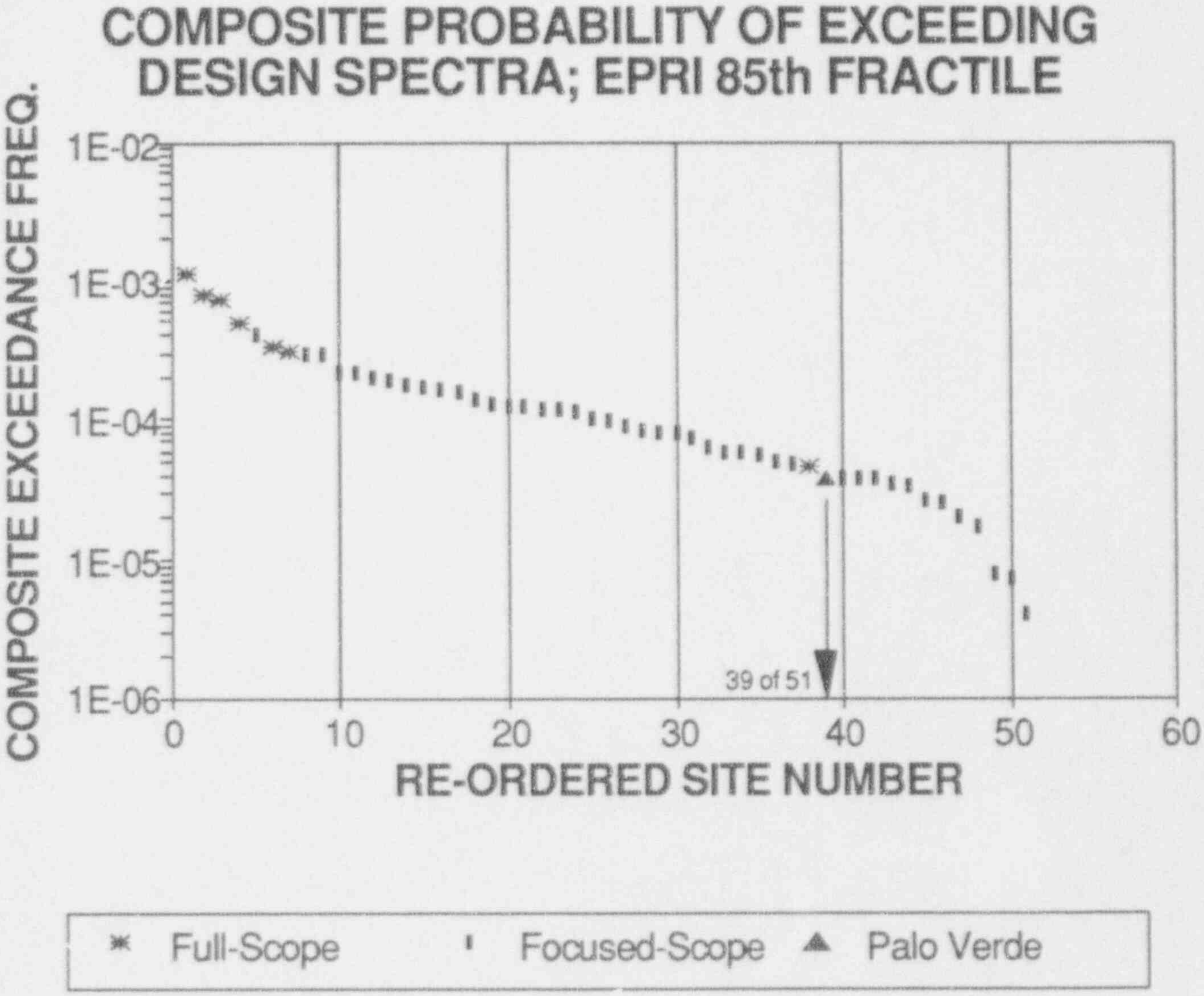


Figure B-6. Comparison of the composite 85th-fractile probability of exceeding the seismic design-basis spectrum: comparison of results for the the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

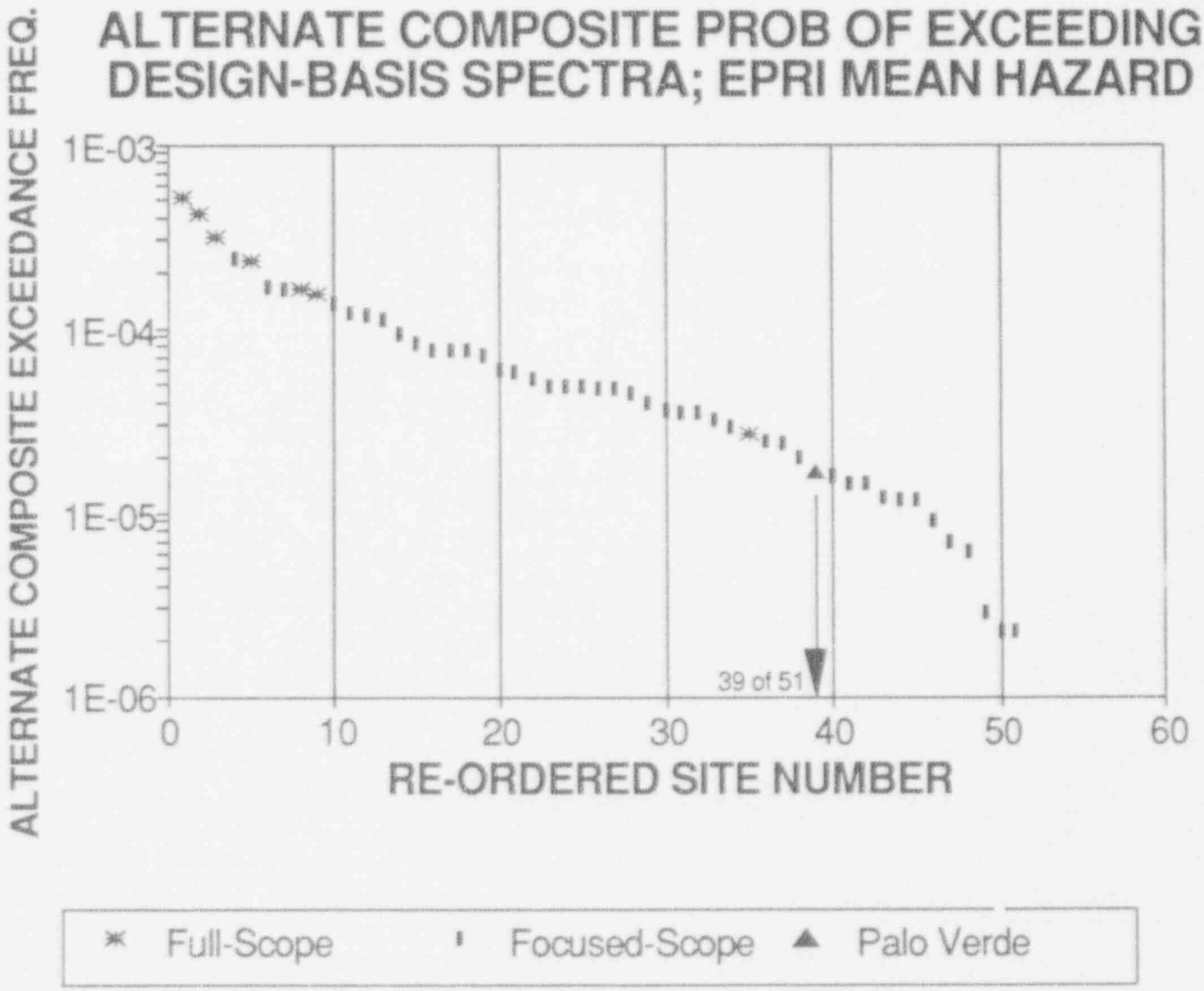


Figure B-7. Comparison of the alternate-composite mean probability of exceeding the seismic design-basis spectrum: comparison of results for the the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

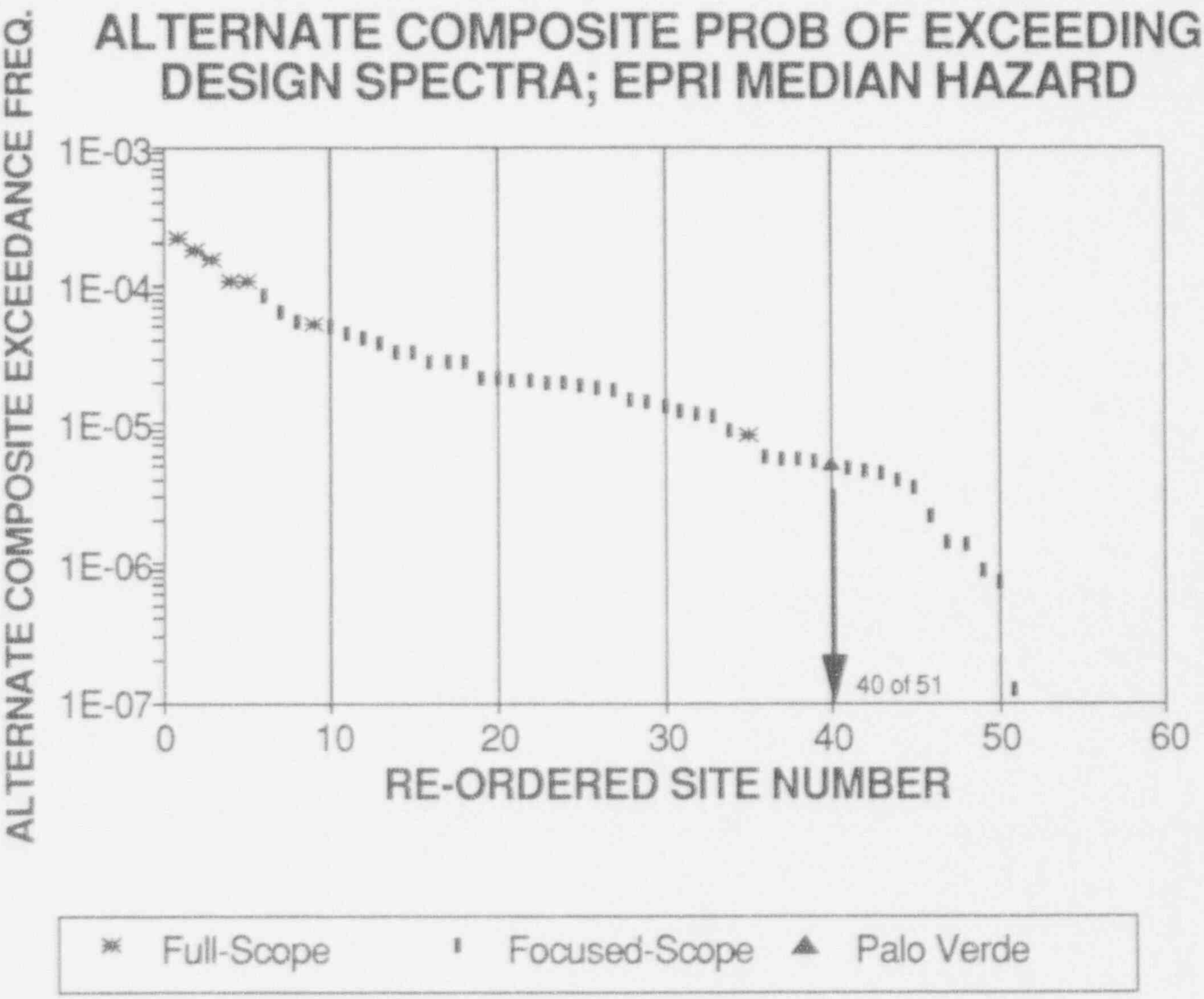


Figure B-8. Comparison of the alternate-composite median probability of exceeding the seismic design-basis spectrum: comparison of results for the the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

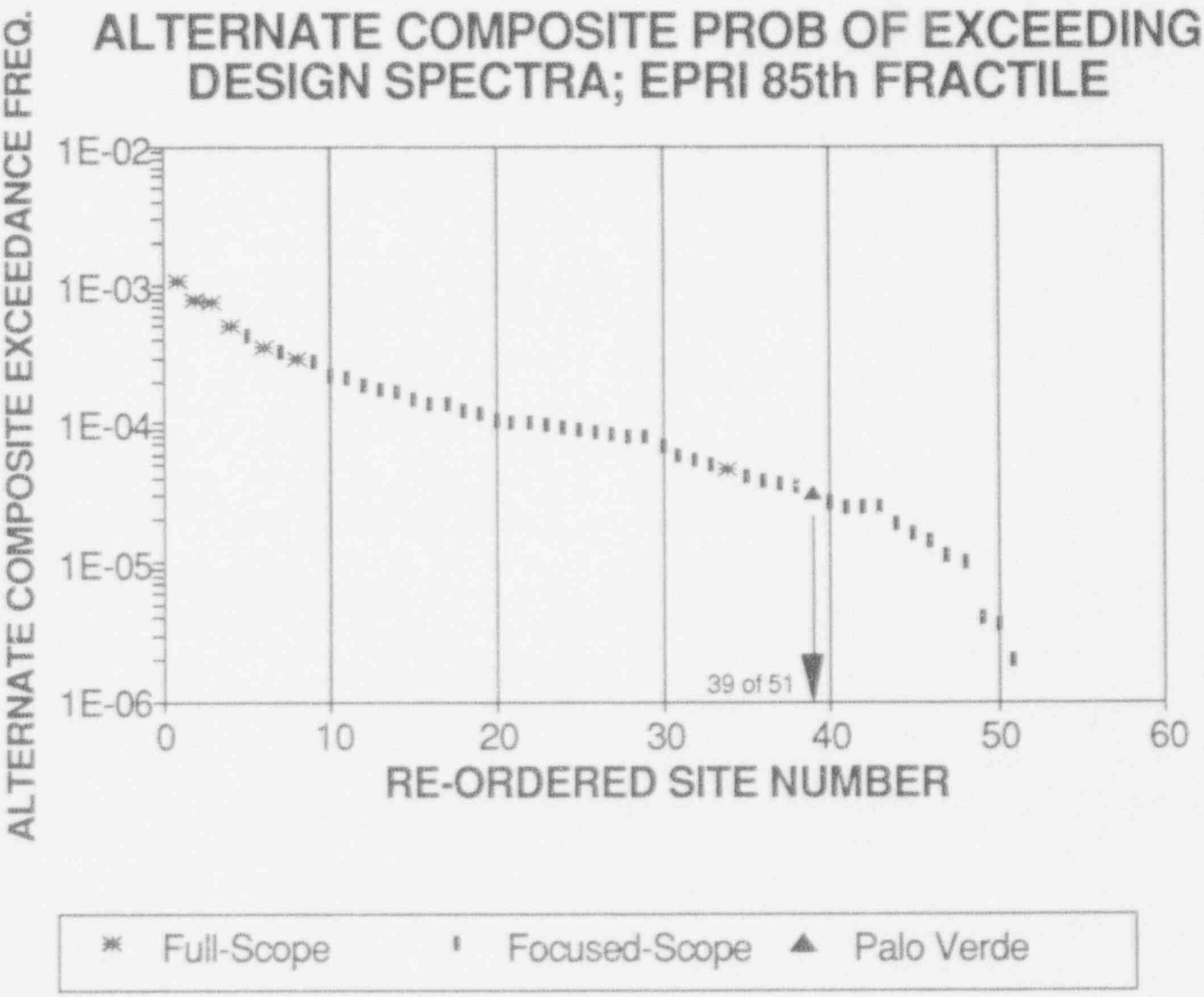


Figure B-9. Comparison of the alternate-composite 85th-fractile probability of exceeding the seismic design-basis spectrum: comparison of results for the the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

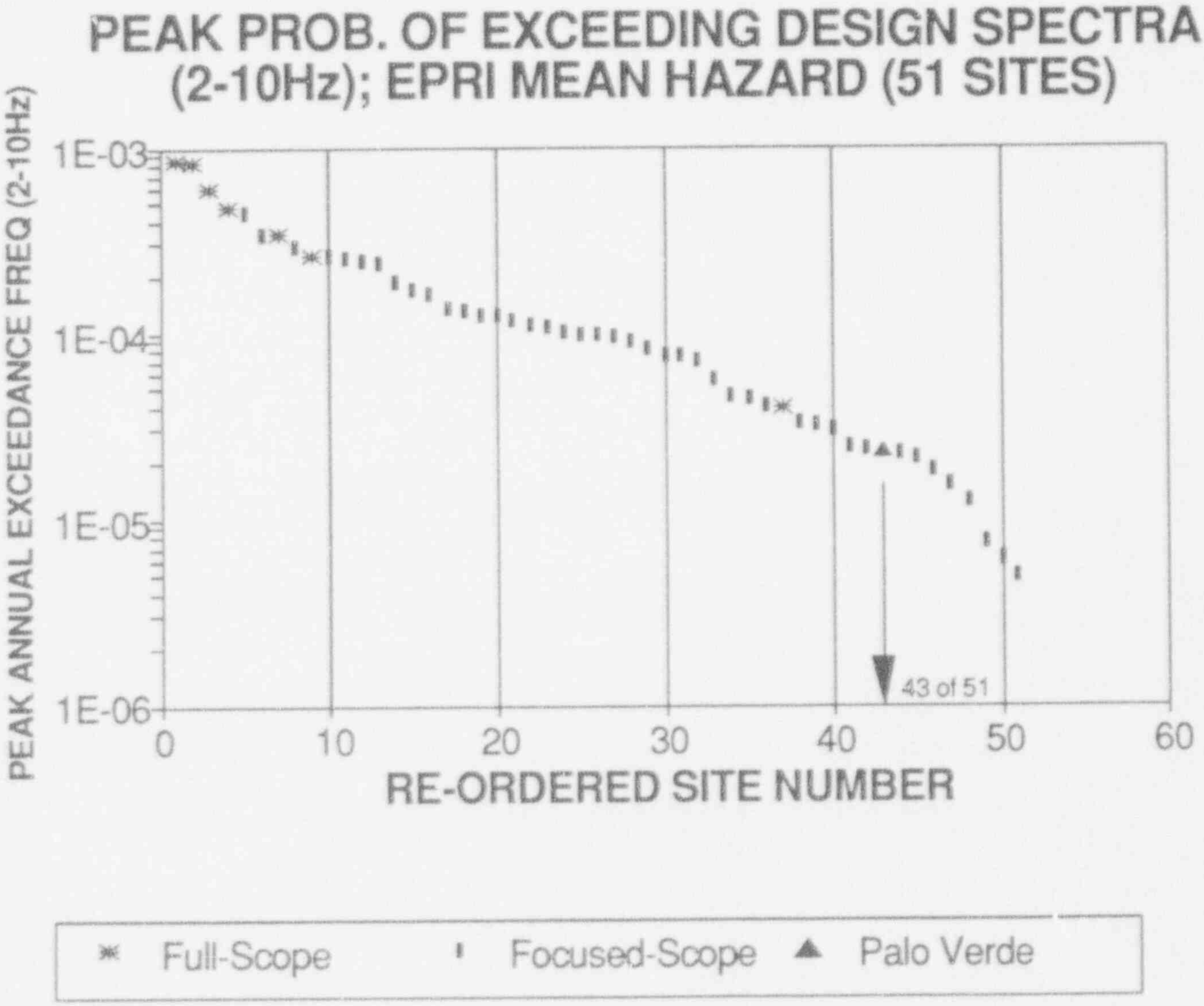


Figure B-10. Comparison of the peak (over the frequency range of 2 to 10 Hz) mean probability of exceeding the seismic design-basis spectrum: comparison of results for the the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

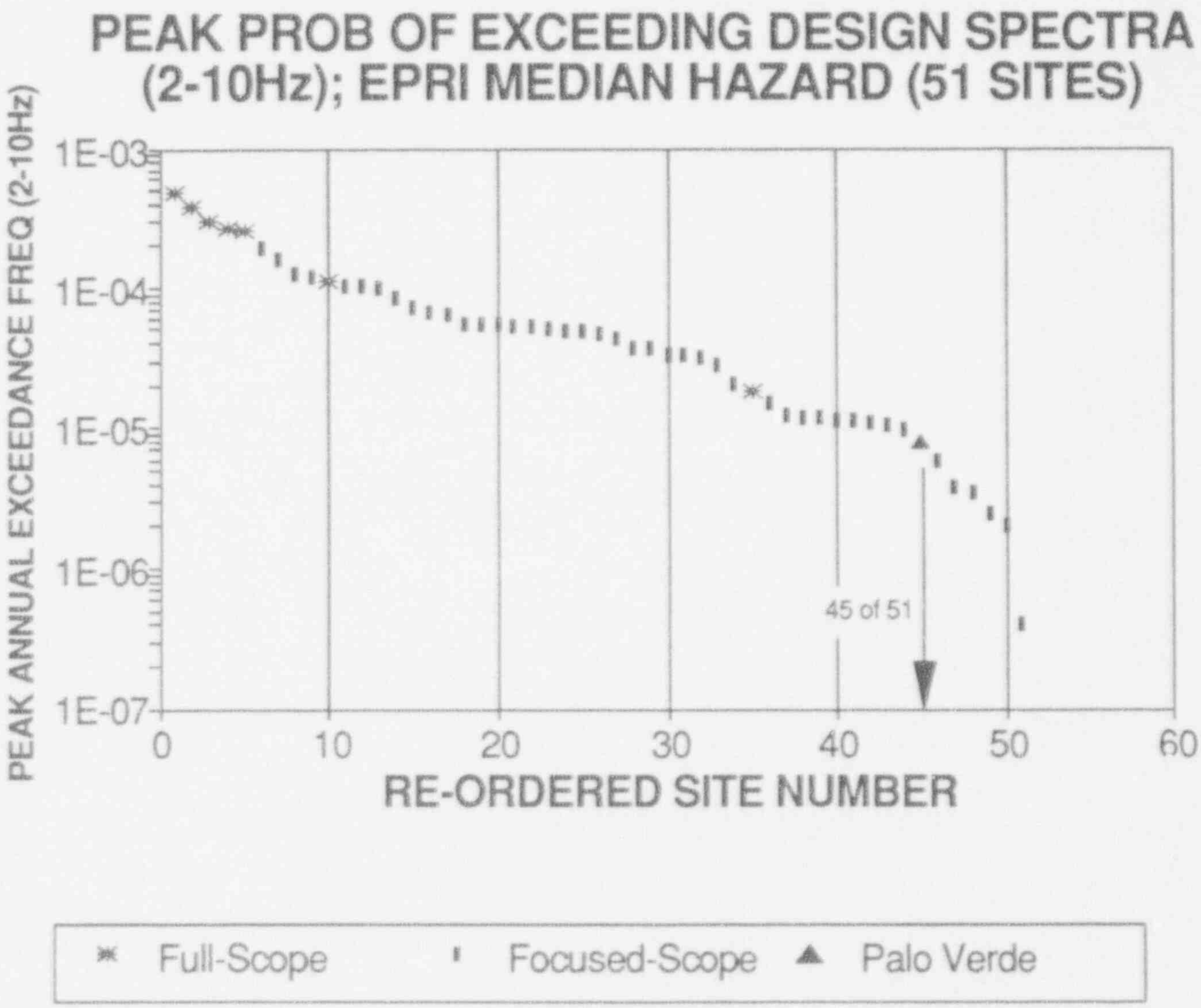


Figure B-11. Comparison of the peak (over the frequency range of 2 to 10 Hz) median probability of exceeding the seismic design-basis spectrum: comparison of results for the the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

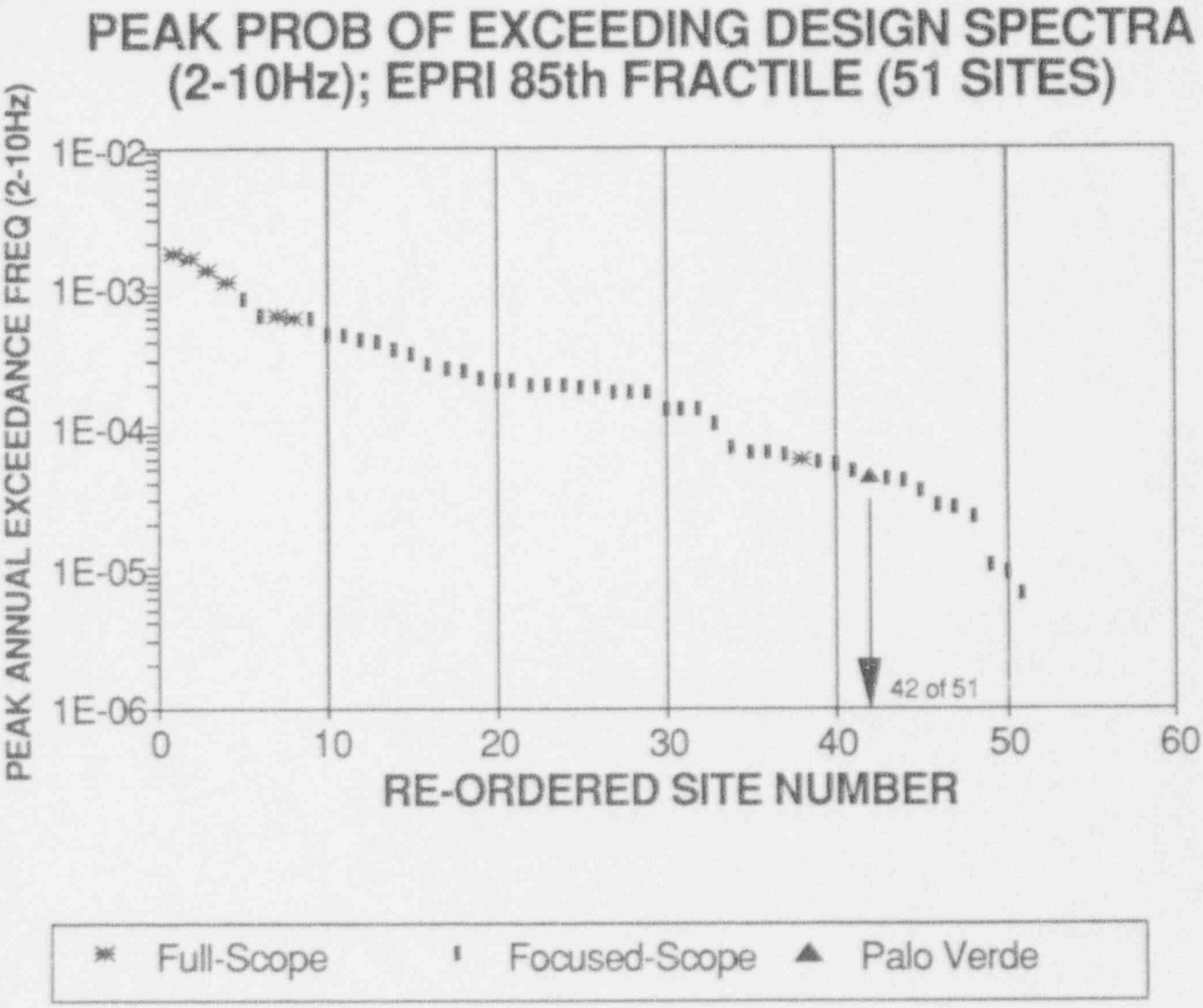


Figure B-12. Comparison of the peak (over the frequency range of 2 to 10 Hz) 85th-fractile probability of exceeding the seismic design-basis spectrum: comparison of results for the the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

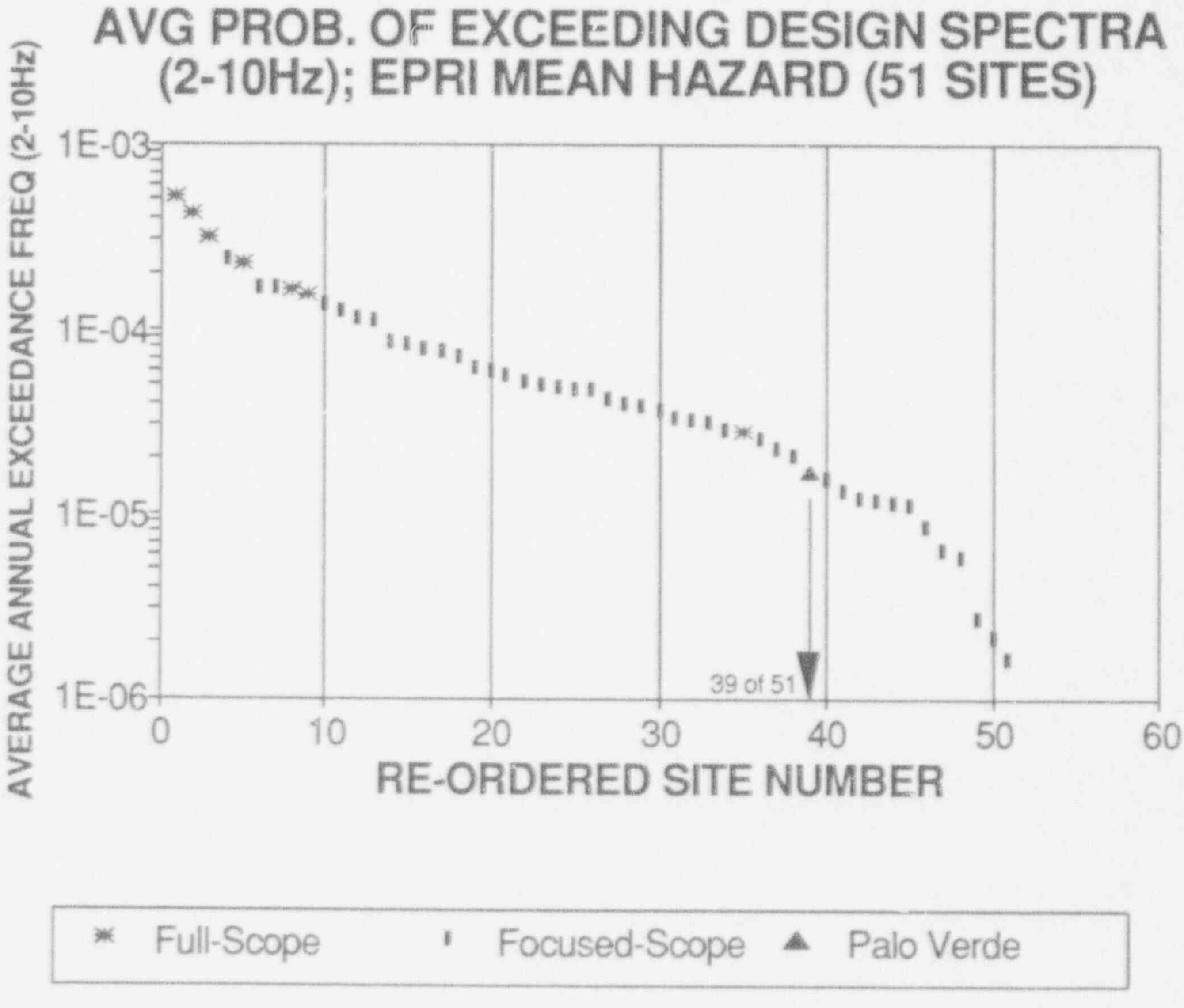


Figure B-13. Comparison of the average (over the frequency range of 2 to 10 Hz) mean probability of exceeding the seismic design-basis spectrum: comparison of results for the the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

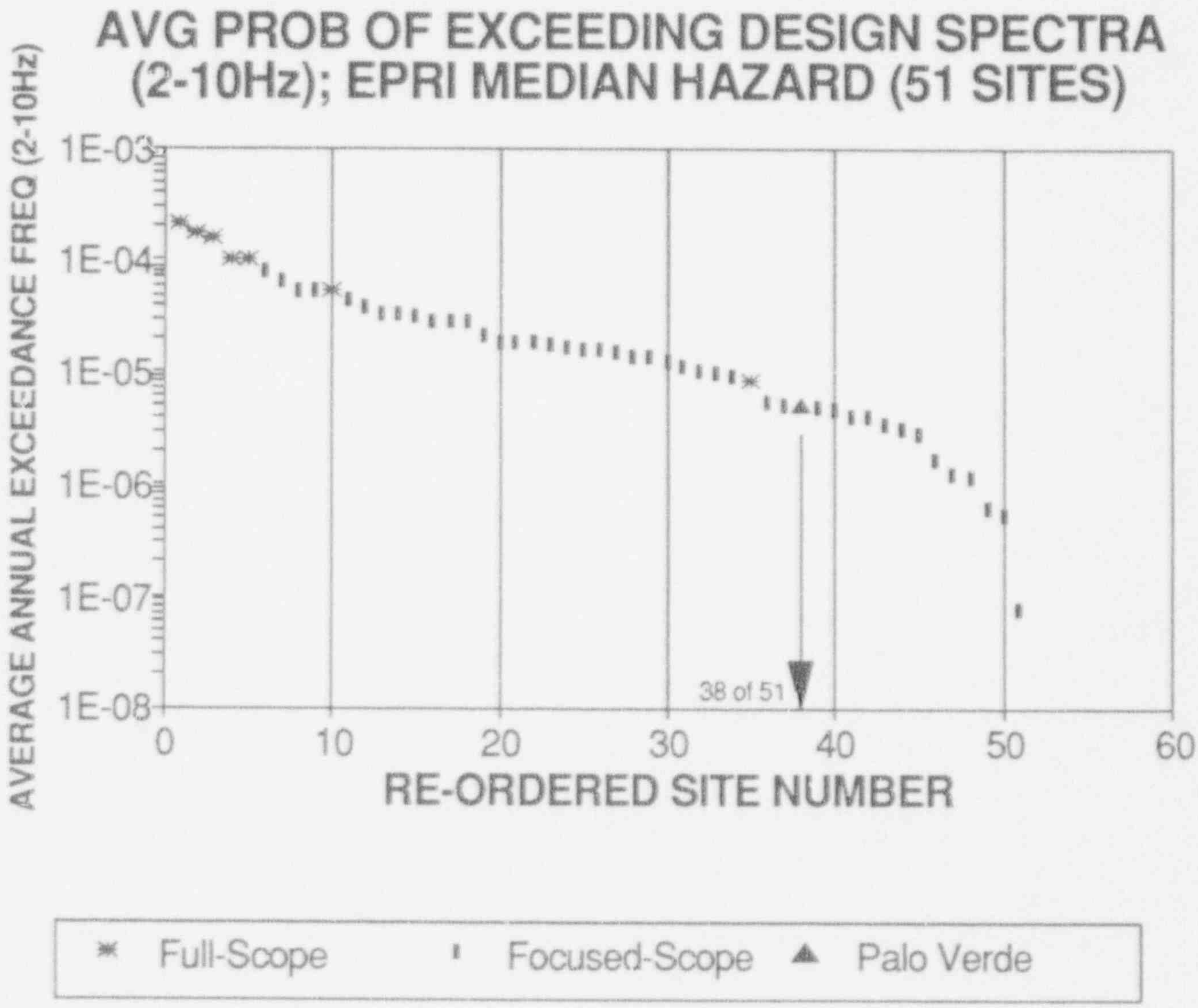


Figure B-14. Comparison of the average (over the frequency range of 2 to 10 Hz) median probability of exceeding the seismic design-basis spectrum: comparison of results for the the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

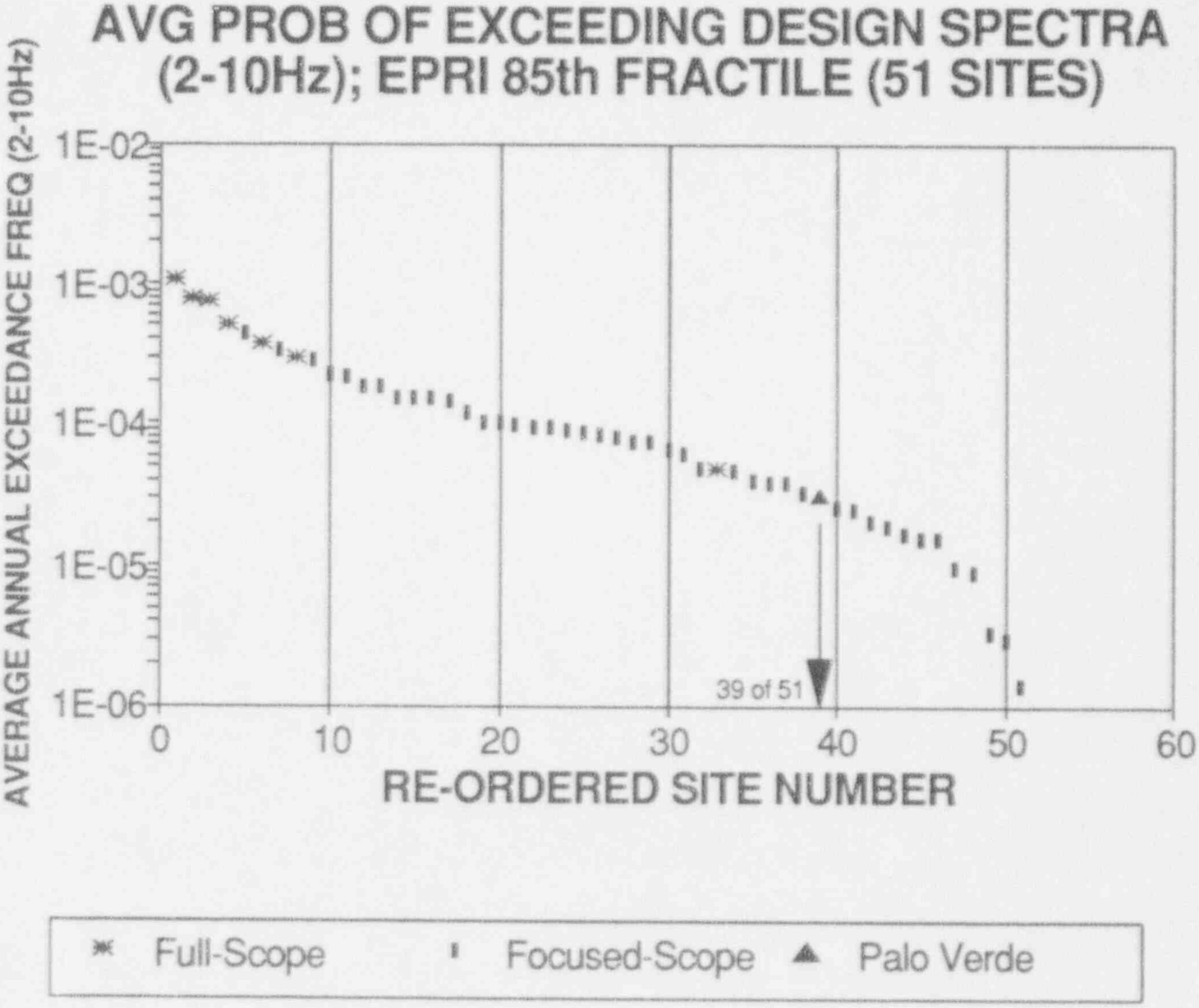


Figure B-15. Comparison of the average (over the frequency range of 2 to 10 Hz) 85th-fractile probability of exceeding the seismic design-basis spectrum: comparison of results for the the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

Appendix C

COMPARISONS OF UNIFORM HAZARD SPECTRA

This appendix presents uniform-hazard ground-motion results for the Palo Verde site and for 50 nuclear power plant locations in the central and eastern United States. Uniform hazard spectra are presented for annual exceedance frequencies of 10^{-3}, 10^{-4}, and 10^{-5}. Scalar measures of spectral acceleration have been derived from these uniform hazard spectra; the scalar measures include peak spectral acceleration over the vibrational-frequency range of 2.0 to 10.0 Hz, and spectral acceleration averaged over the same frequency range. These scalar measures are also presented for annual exceedance frequencies of 10^{-3}, 10^{-4}, and 10^{-5}. In all cases (for uniform-hazard spectra or for derived scalar measures) comparisons are provided for the mean, median, and 85th-fractile hazards.

Hazard results for the 50 central and eastern U.S. sites are based on the EPRI methodology. The 50 sites are comprised of the 0.3g full-scope and focused-scope plants for which EPRI hazard results have been obtained; seven of these plants are full-scope plants, and the remaining 43 are focused-scope plants.

Figures C–1 to C–3 present, respectively, the 10^{-3} uniform-hazard spectra results for the mean, median, and 85th-fractile hazards. The sets of graphs in Figures C–4 to C–6 and Figures C–7 to C–9 present similar results, respectively, for the 10^{-4} and 10^{-5} hazard levels.

[In these spectral plots, results of uniform-hazard peak ground accelerations (PGAs) are indicated by horizontal lines from 65.0 to 100.0 Hz. Consistent with results produced from the seismic hazard investigation for PVNGS and the other plants, spectra have not been computed nor plotted over the frequency range of 25 to 65 Hz. To estimate how the spectrum varies over this frequency range for PVNGS, simply connect the point at 25 Hz to a point at 33 Hz that matches the PGA, and then extend a horizontal line across to 65 Hz (i.e., spectral accelerations beyond 33 Hz are assumed to correspond to the PGA). For central/eastern U.S. sites, extend the spectrum linearly beyond 25 Hz to 35 Hz, and then connect the resulting point at 35 Hz to the PGA value at 65 Hz (i.e., the peak spectral acceleration usually occurs at 35 Hz, and spectral accelerations beyond 65 Hz are assumed to correspond to the PGA)].

Figures C–10 to C–18 present plots of peak uniform-hazard spectral acceleration occurring over the vibrational-frequency range of 2 to 10 Hz. Here, each ordered plot presents a

comparison of scalar measures corresponding to the respective comparisons of uniform hazard spectra just described for Figures C–1 to C–9.

Figures C–19 to C–27 present plots of uniform-hazard spectral acceleration averaged over the vibrational-frequency range of 2 to 10 Hz. Again, each ordered plot presents a comparison of scalar measures corresponding to the respective comparisons of uniform hazard spectra described for Figures C–1 to C–9.

The plots presented in this appendix support the comparisons and observations made in Section 5 of this report, and provide the basis for developing the plant rankings indicated in Table 5-2.

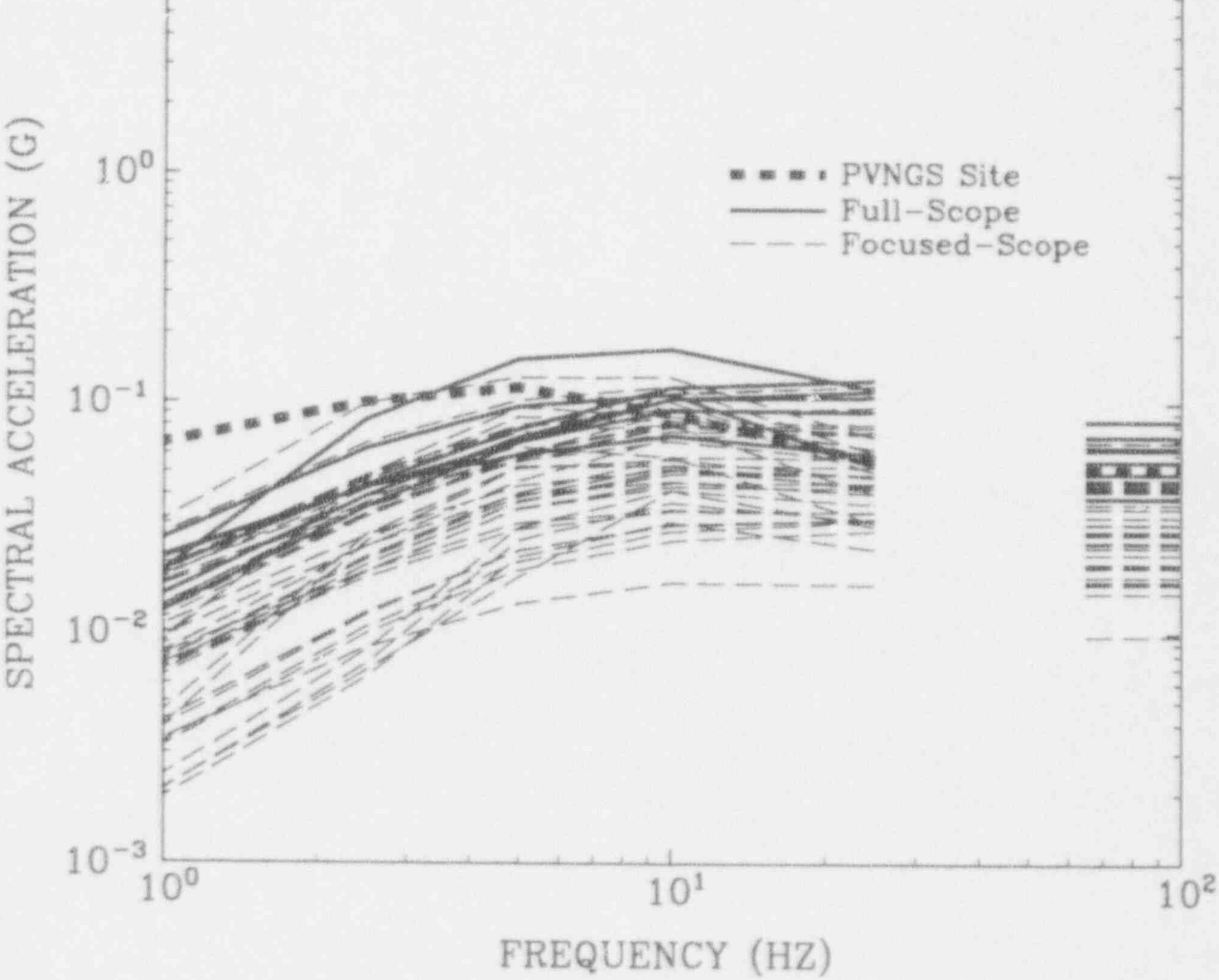


Figure C-1. Comparison of the 10^{-3} mean uniform hazard spectrum for the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S. (Values for PGA are indicated by horizontal lines plotted from 65 to 100 Hz).

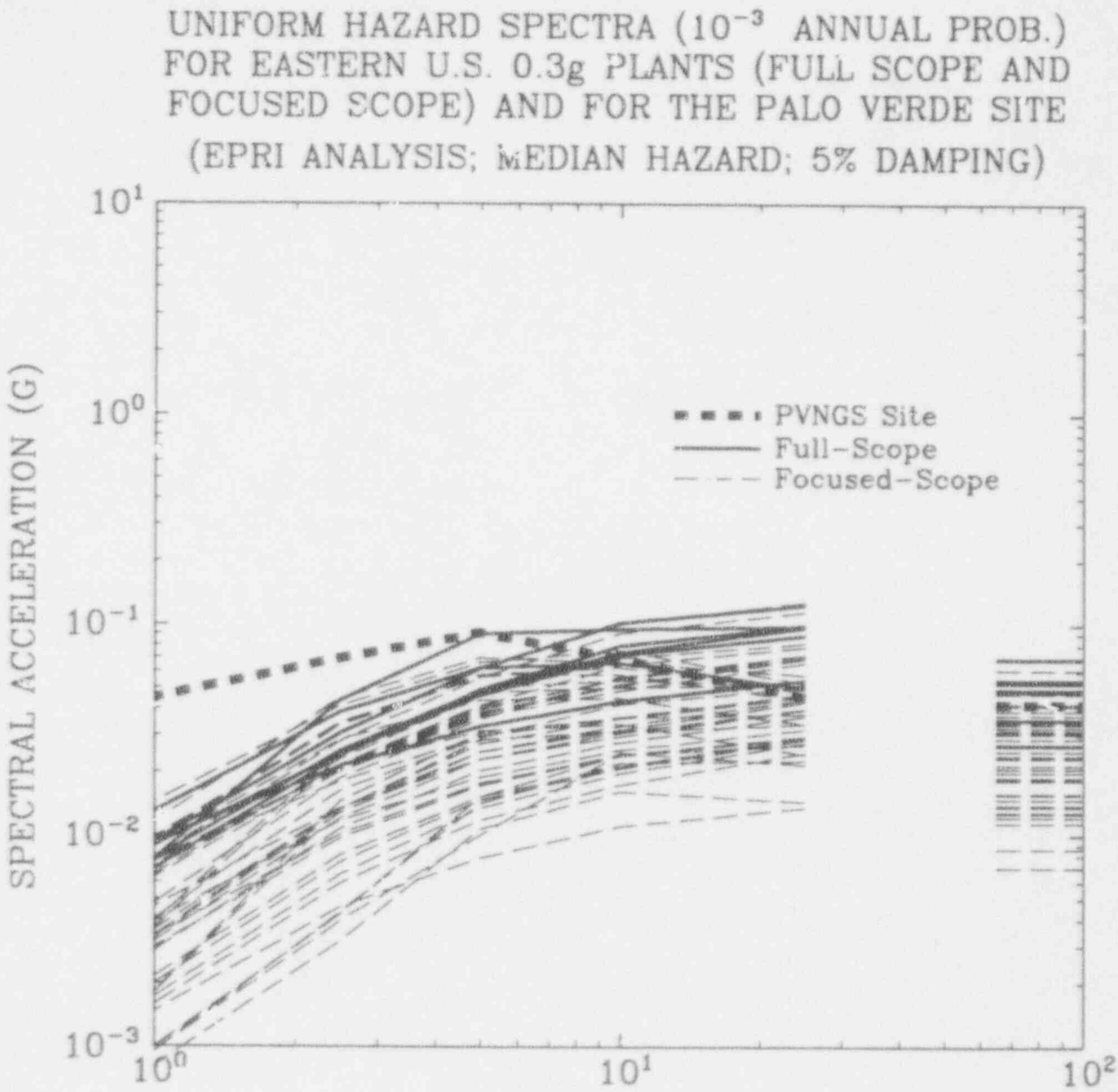


Figure C-2. Comparison of the 10^{-3} median uniform hazard spectrum for the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S. (Values for PGA are indicated by horizontal lines plotted from 65 to 100 Hz).

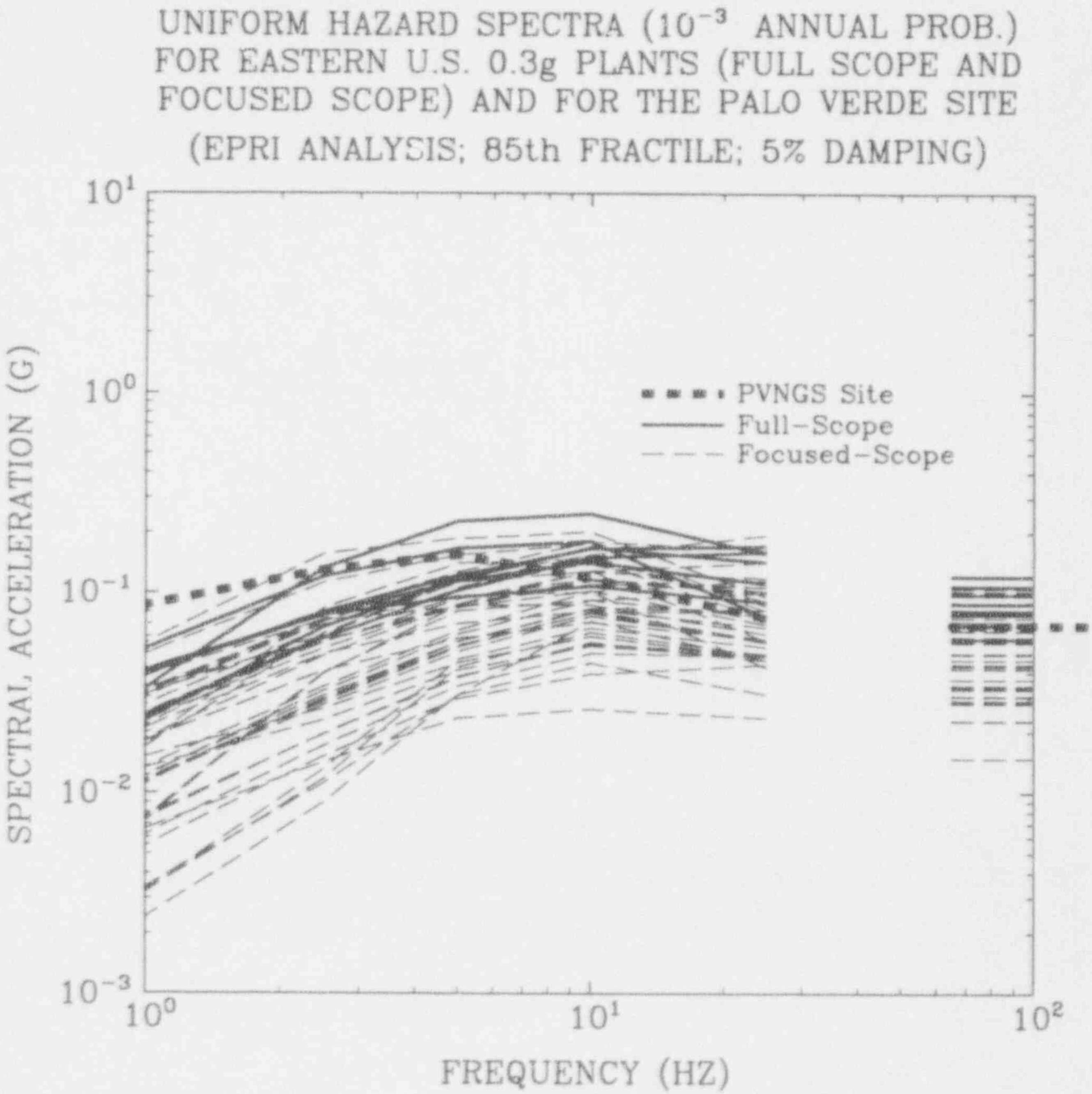


Figure C-3. Comparison of the 10^{-3} 85th-fractile uniform hazard spectrum for the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S. (Values for PGA are indicated by horizontal lines plotted from 65 to 100 Hz).

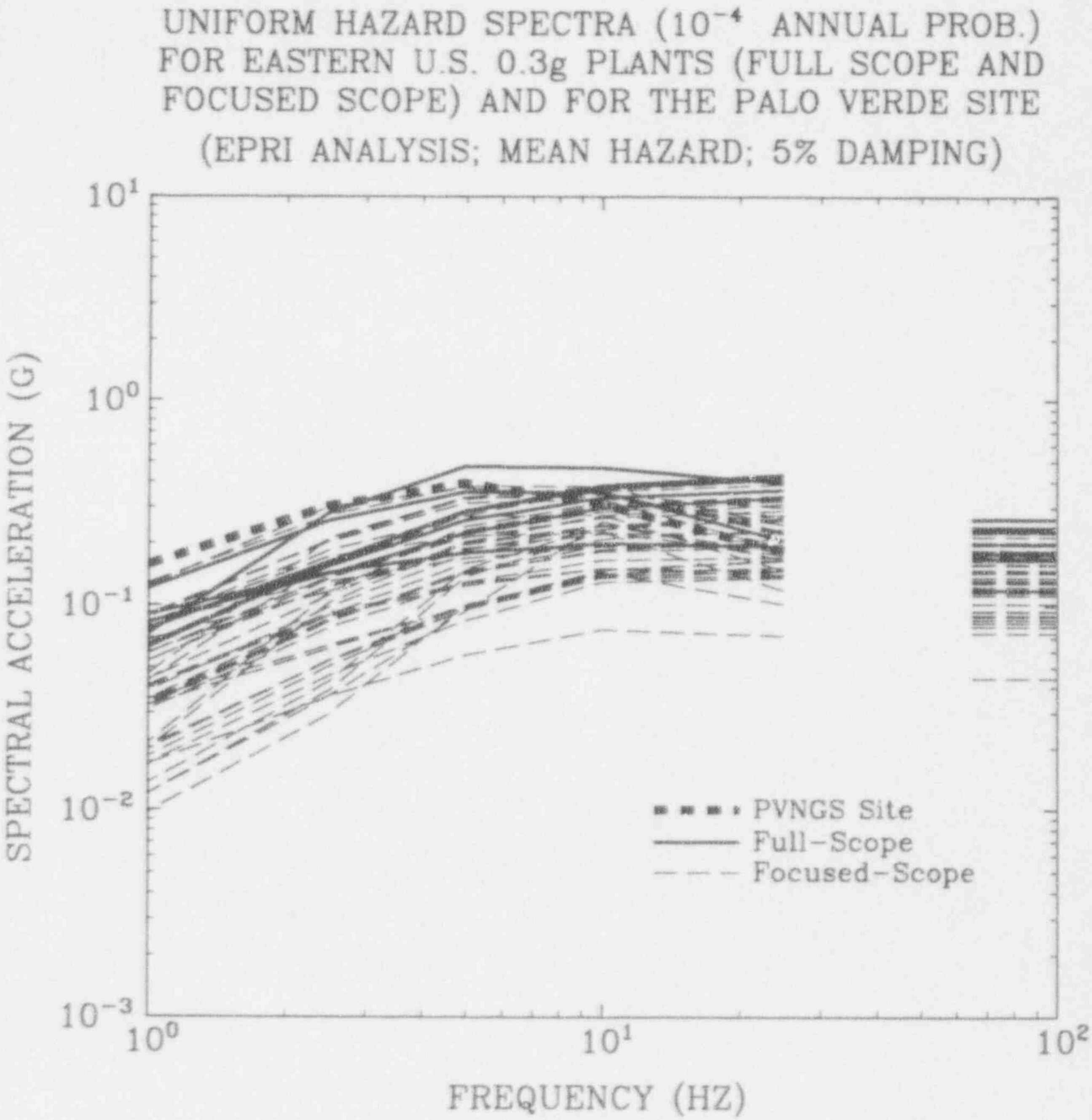


Figure C-4. Comparison of the 10^{-4} mean uniform hazard spectrum for the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S. (Values for PGA are indicated by horizontal lines plotted from 65 to 100 Hz).

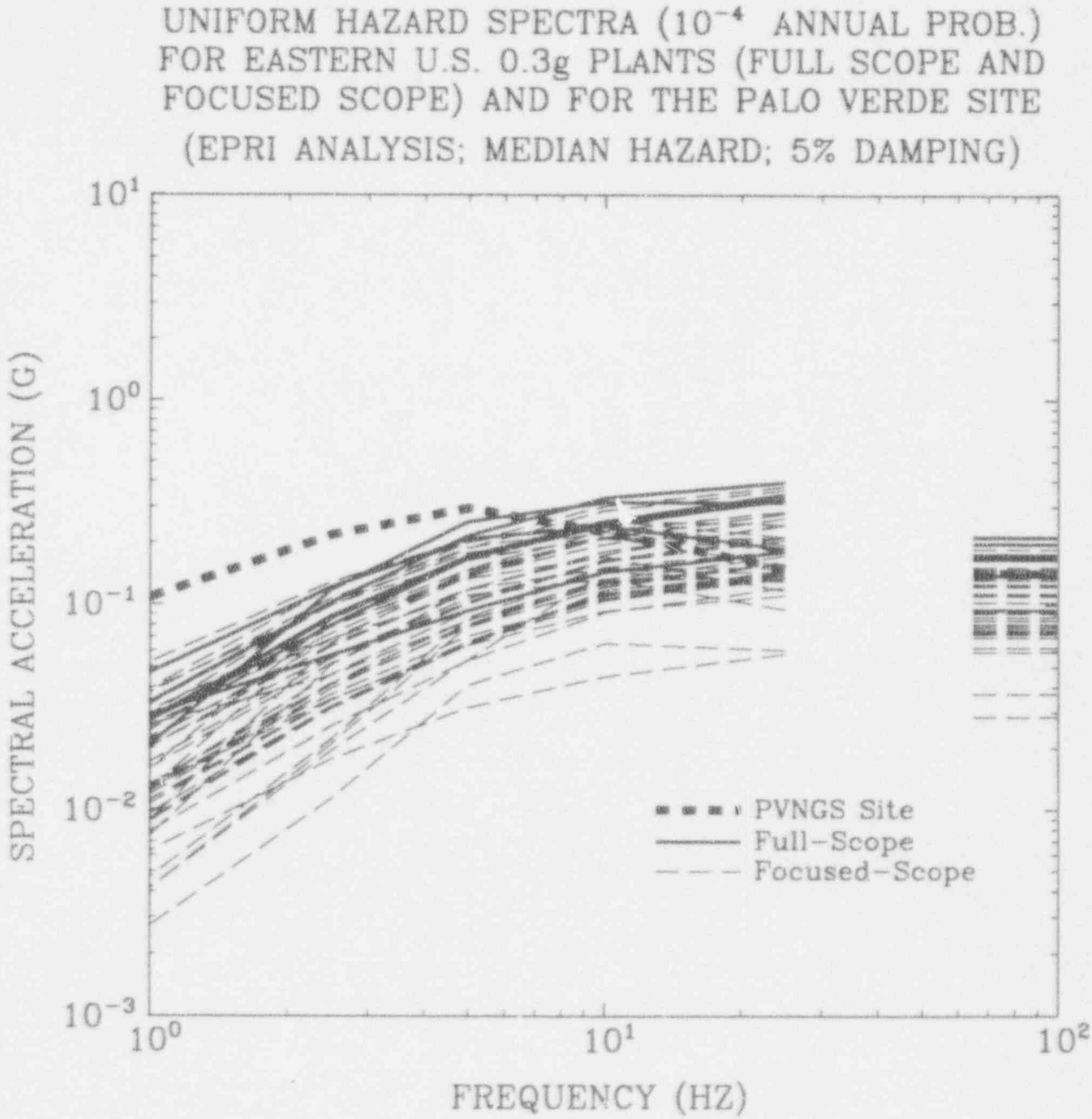


Figure C-5. Comparison of the 10^{-4} median uniform hazard spectrum for the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S. (Values for PGA are indicated by horizontal lines plotted from 65 to 100 Hz).

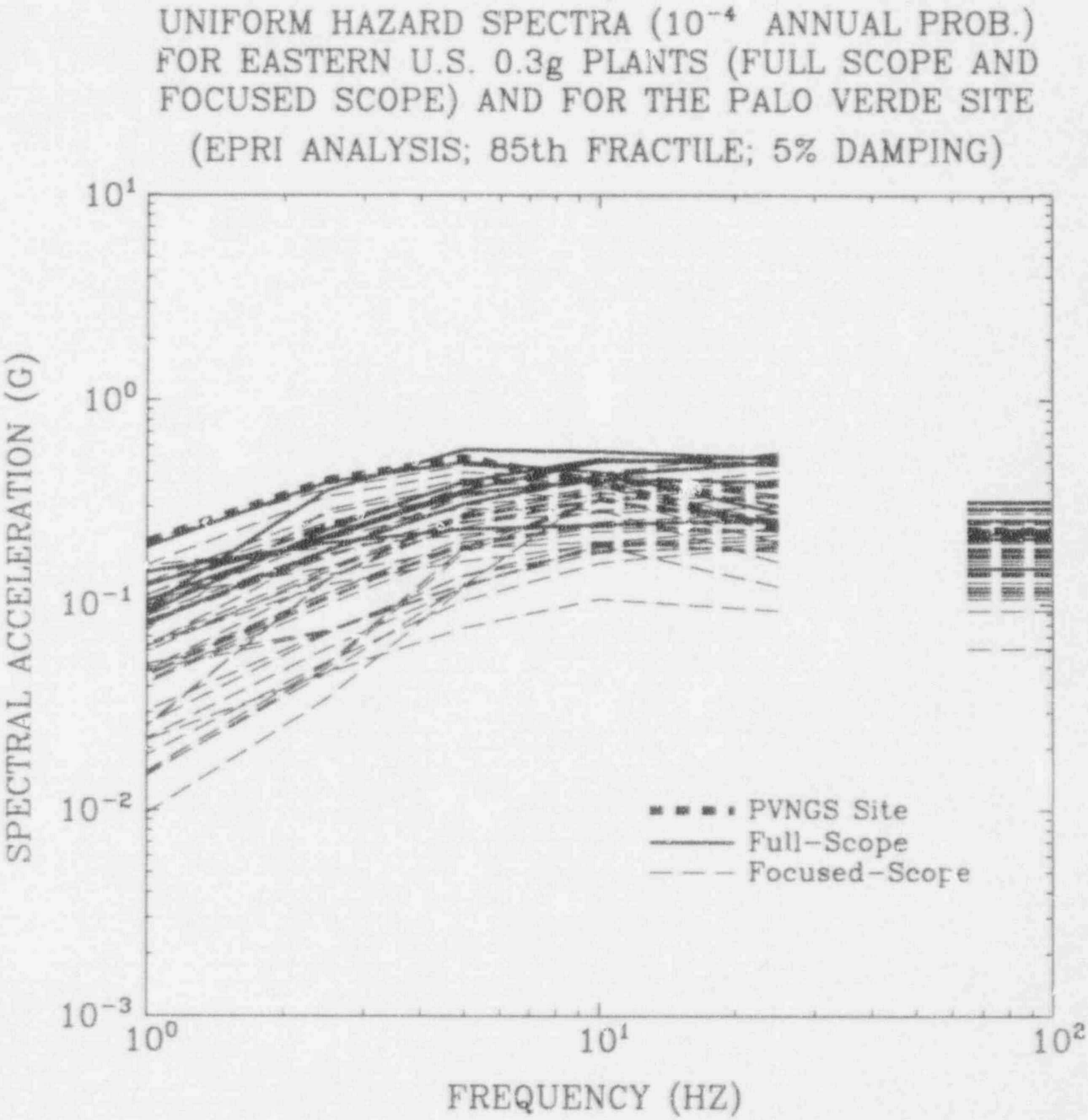


Figure C-6. Comparison of the 10^{-4} 85th-fractile uniform hazard spectrum for the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S. (Values for PGA are indicated by horizontal lines plotted from 65 to 100 Hz).

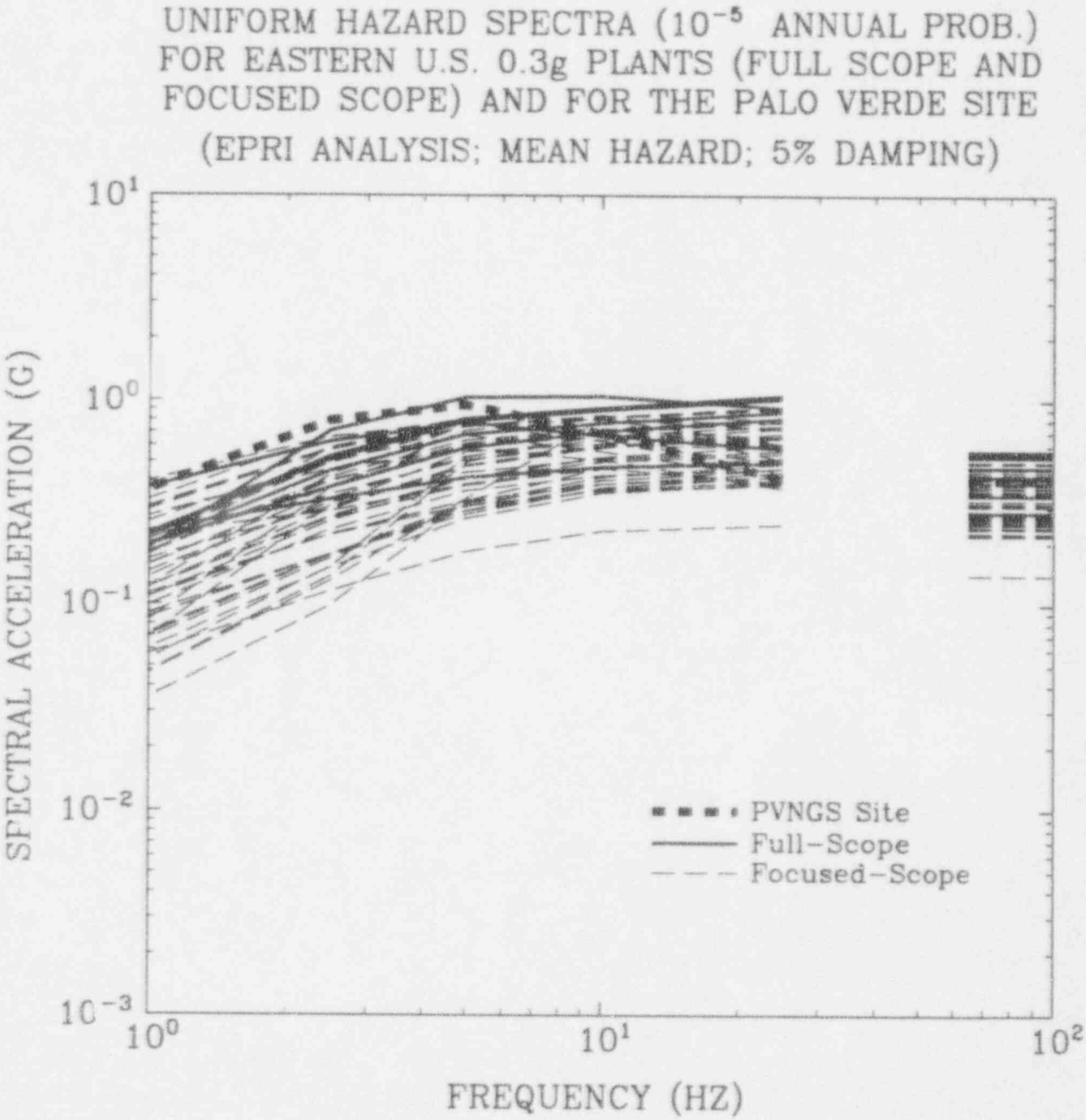


Figure C-7. Comparison of the 10^{-5} mean uniform hazard spectrum for the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S. (Values for PGA are indicated by horizontal lines plotted from 65 to 100 Hz).

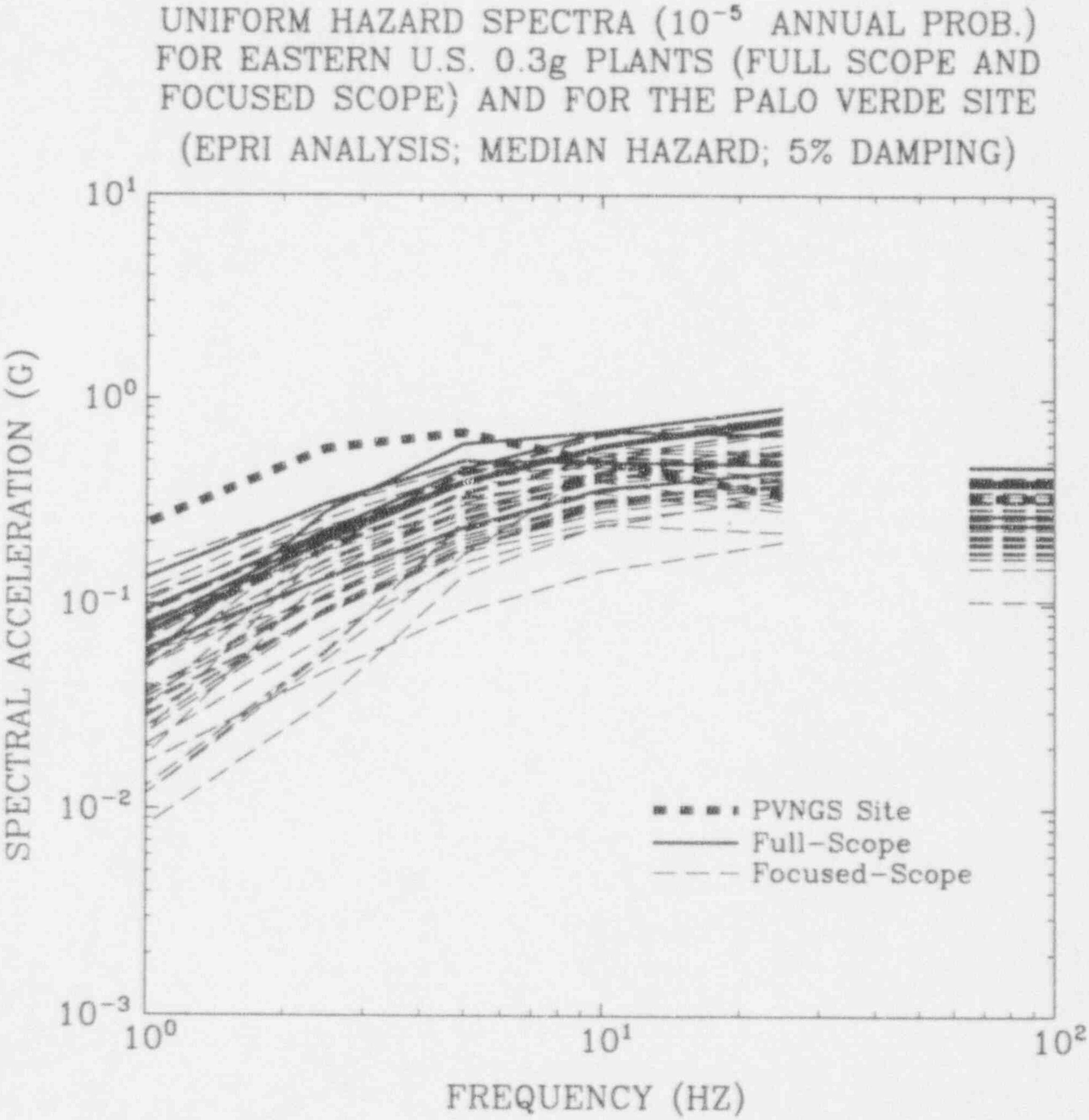


Figure C-8. Comparison of the 10^{-5} median uniform hazard spectrum for the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S. (Values for PGA are indicated by horizontal lines plotted from 65 to 100 Hz).

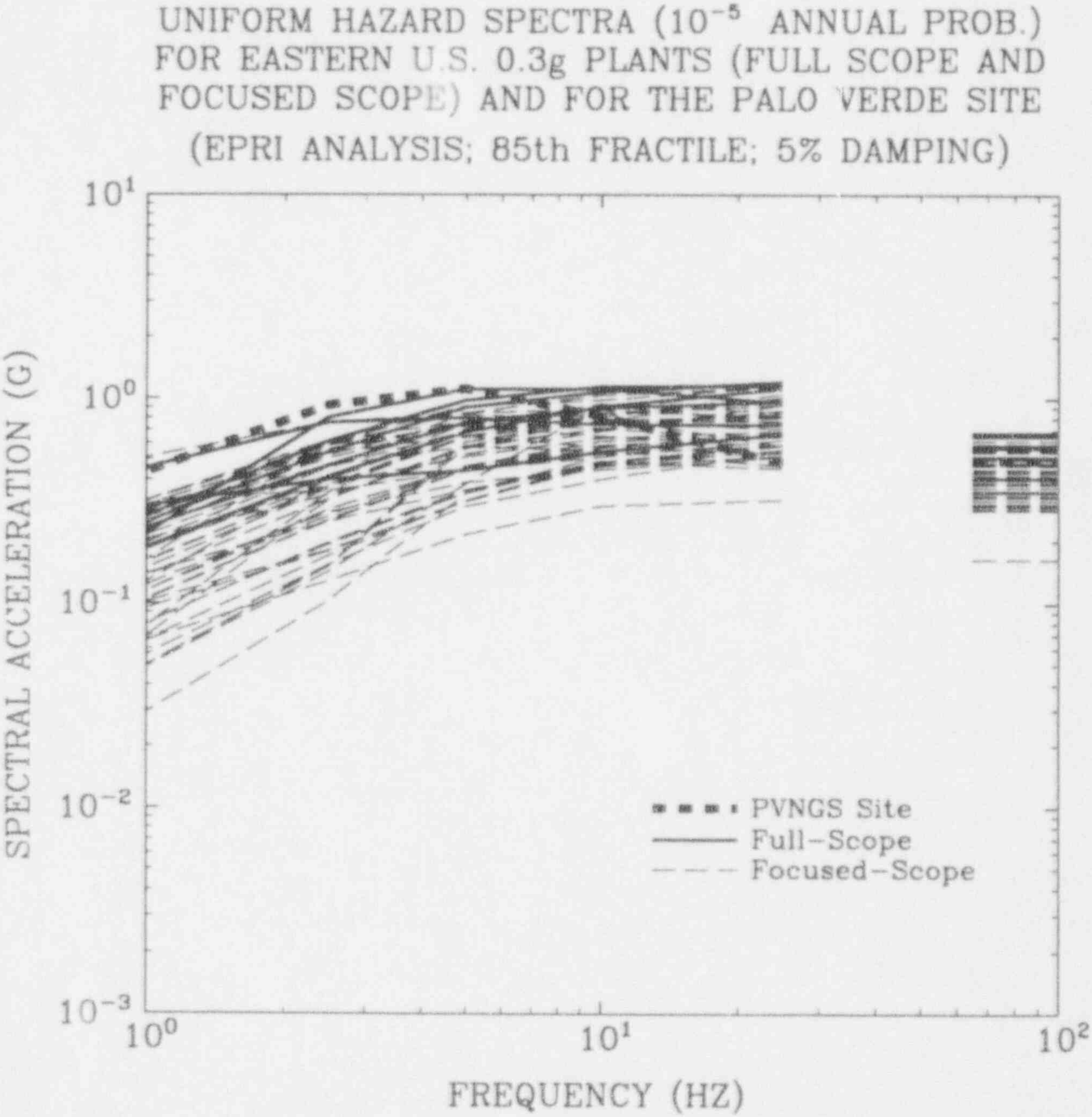


Figure C-9. Comparison of the 10^{-5} 85th-fractile uniform hazard spectrum for the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S. (Values for PGA are indicated by horizontal lines plotted from 65 to 100 Hz).

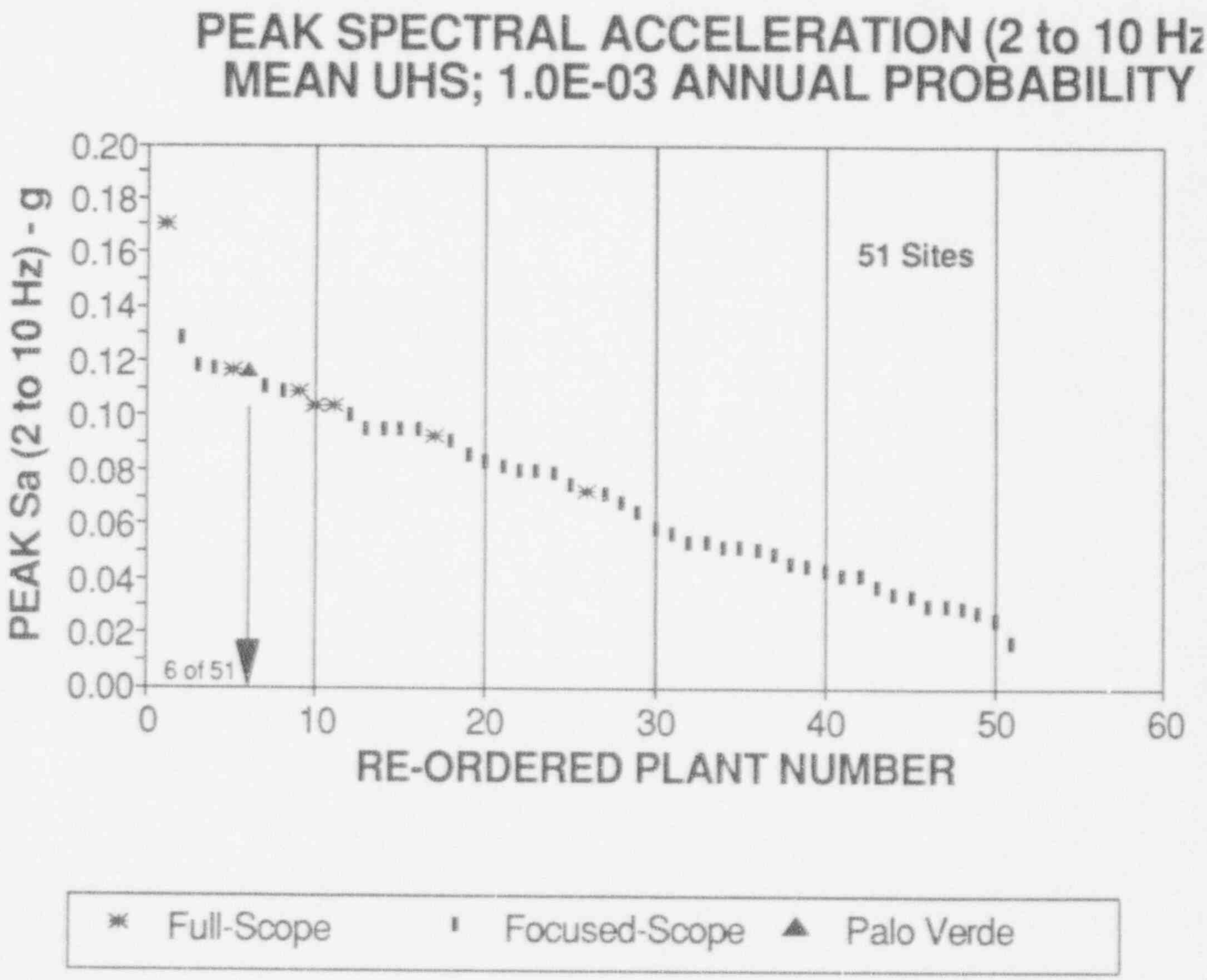


Figure C-10. Comparison of the peak (over the frequency range of 2 to 10 Hz) 10^{-3} mean spectral acceleration for the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

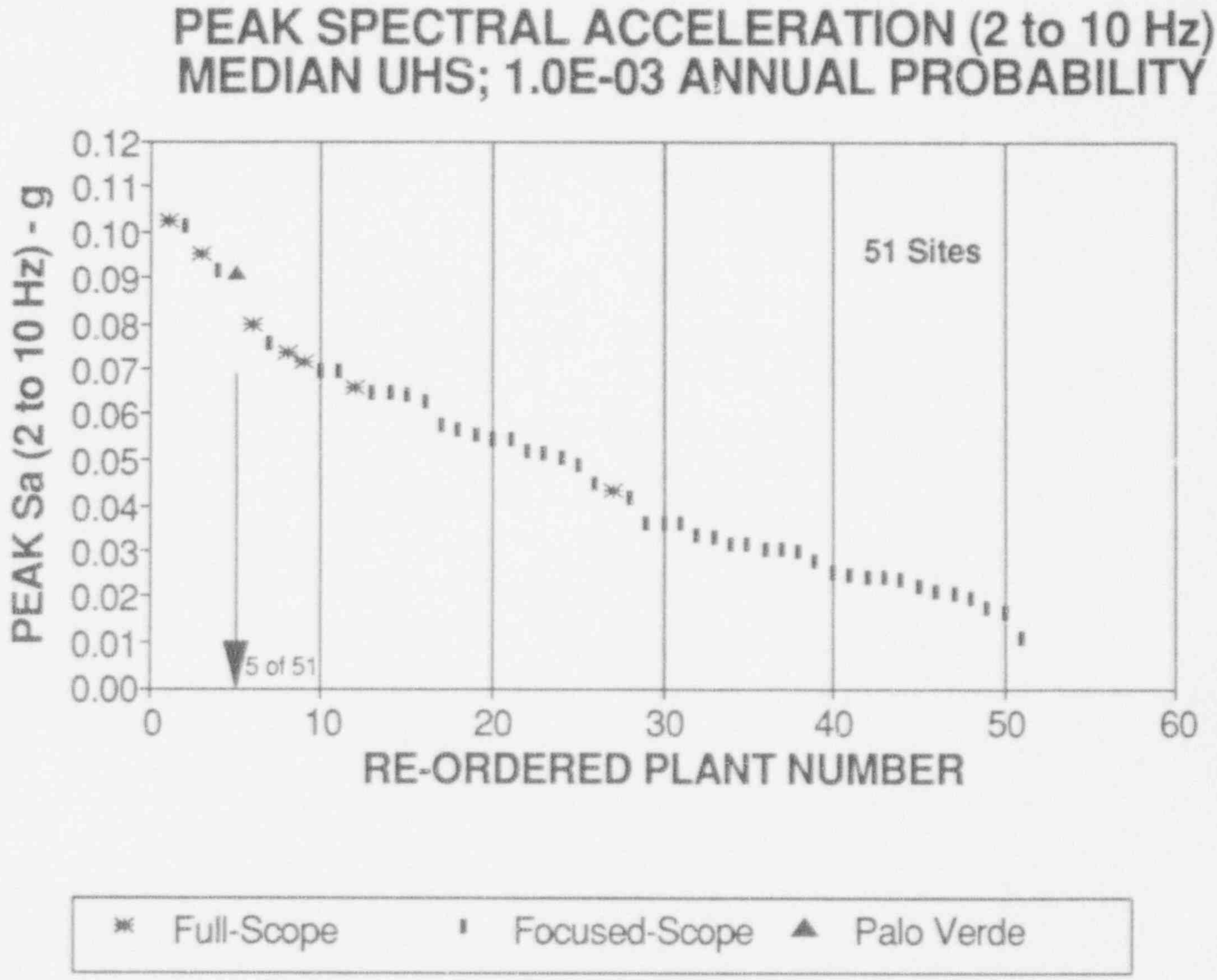


Figure C-11. Comparison of the peak (over the frequency range of 2 to 10 Hz) 10^{-3} median spectral acceleration for the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

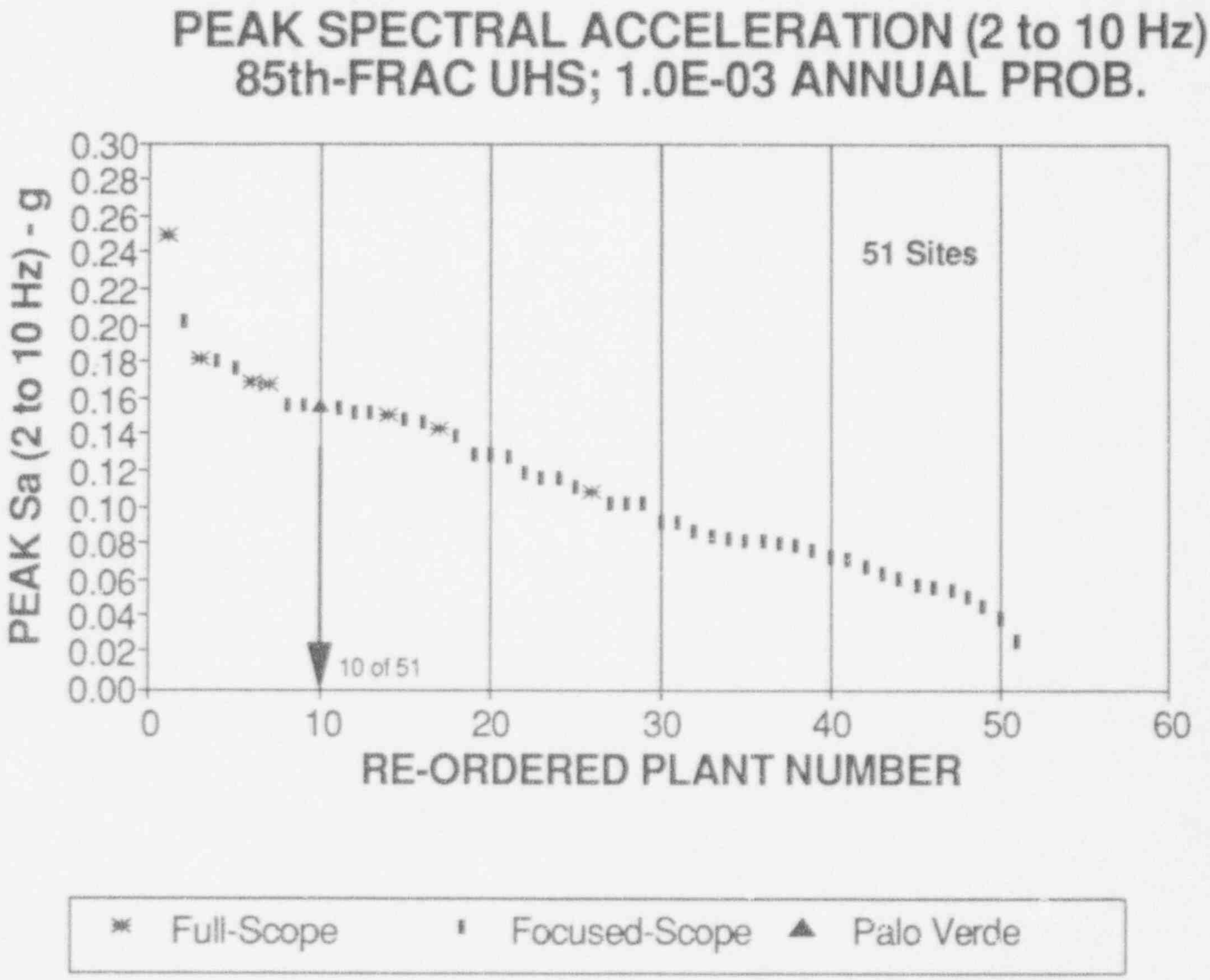


Figure C-12. Comparison of the peak (over the frequency range of 2 to 10 Hz) 10^{-3} 85th-fractile spectral acceleration for the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

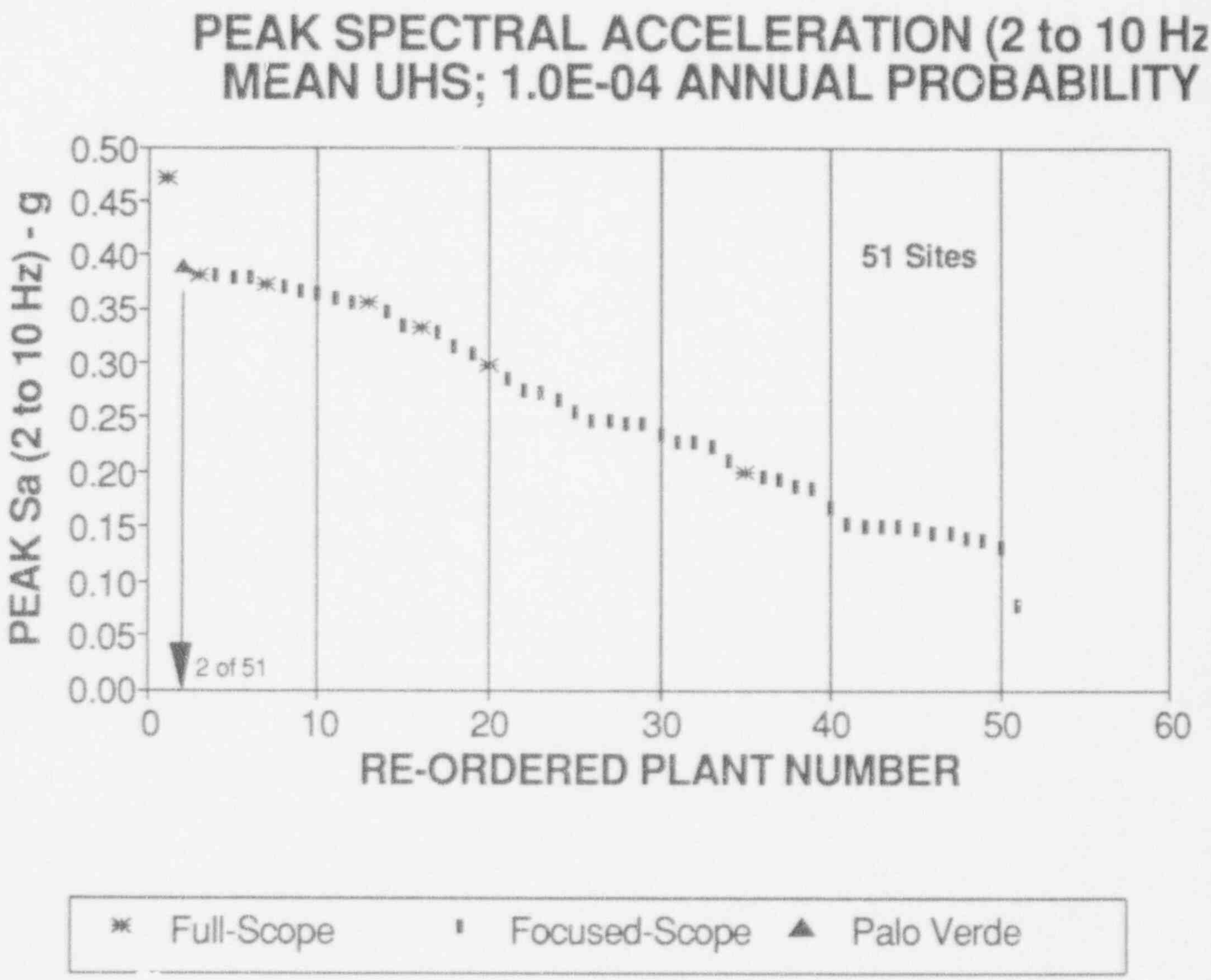


Figure C-13. Comparison of the peak (over the frequency range of 2 to 10 Hz) 10^{-4} mean spectral acceleration for the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

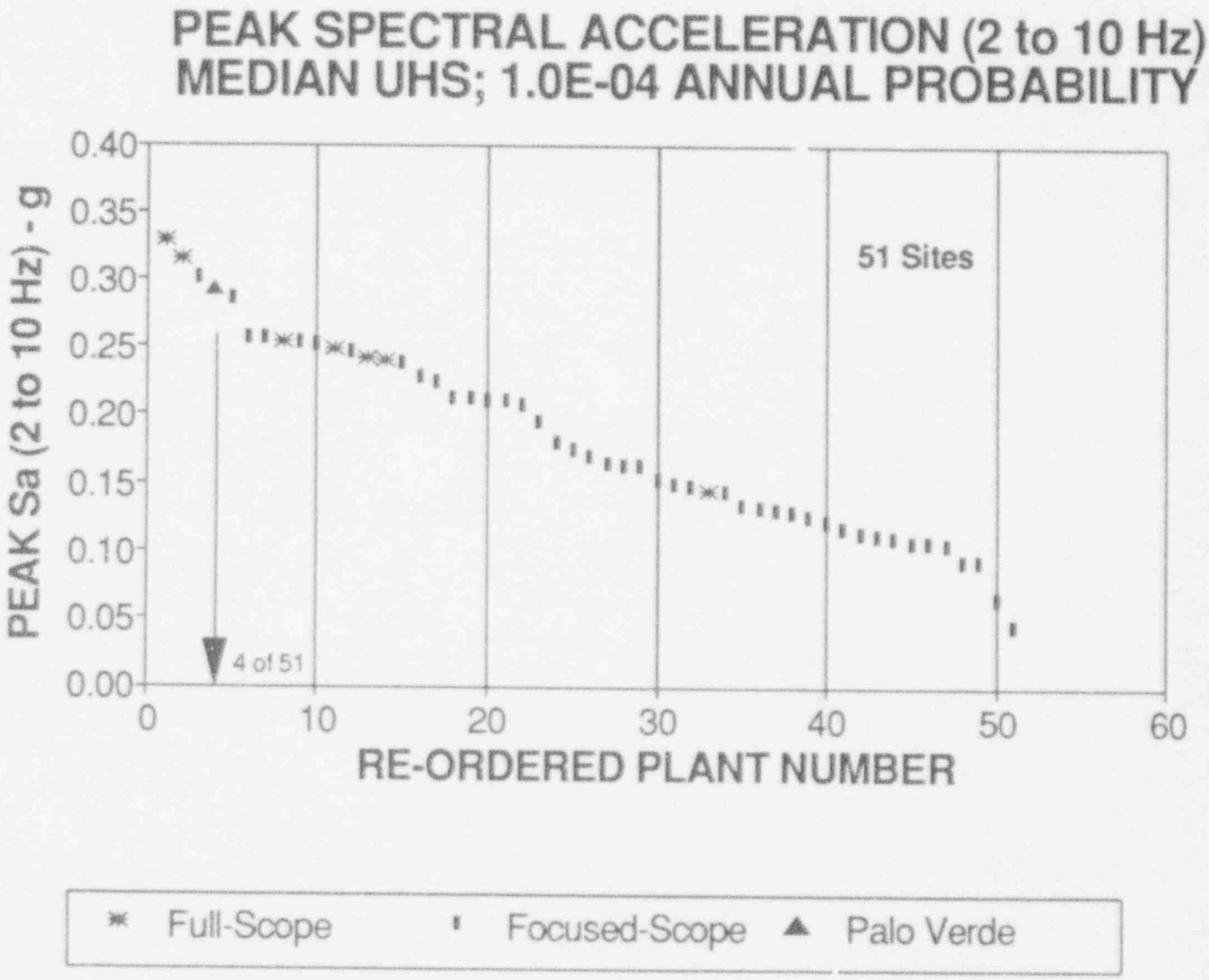


Figure C-14. Comparison of the peak (over the frequency range of 2 to 10 Hz) 10^{-4} median spectral acceleration for the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

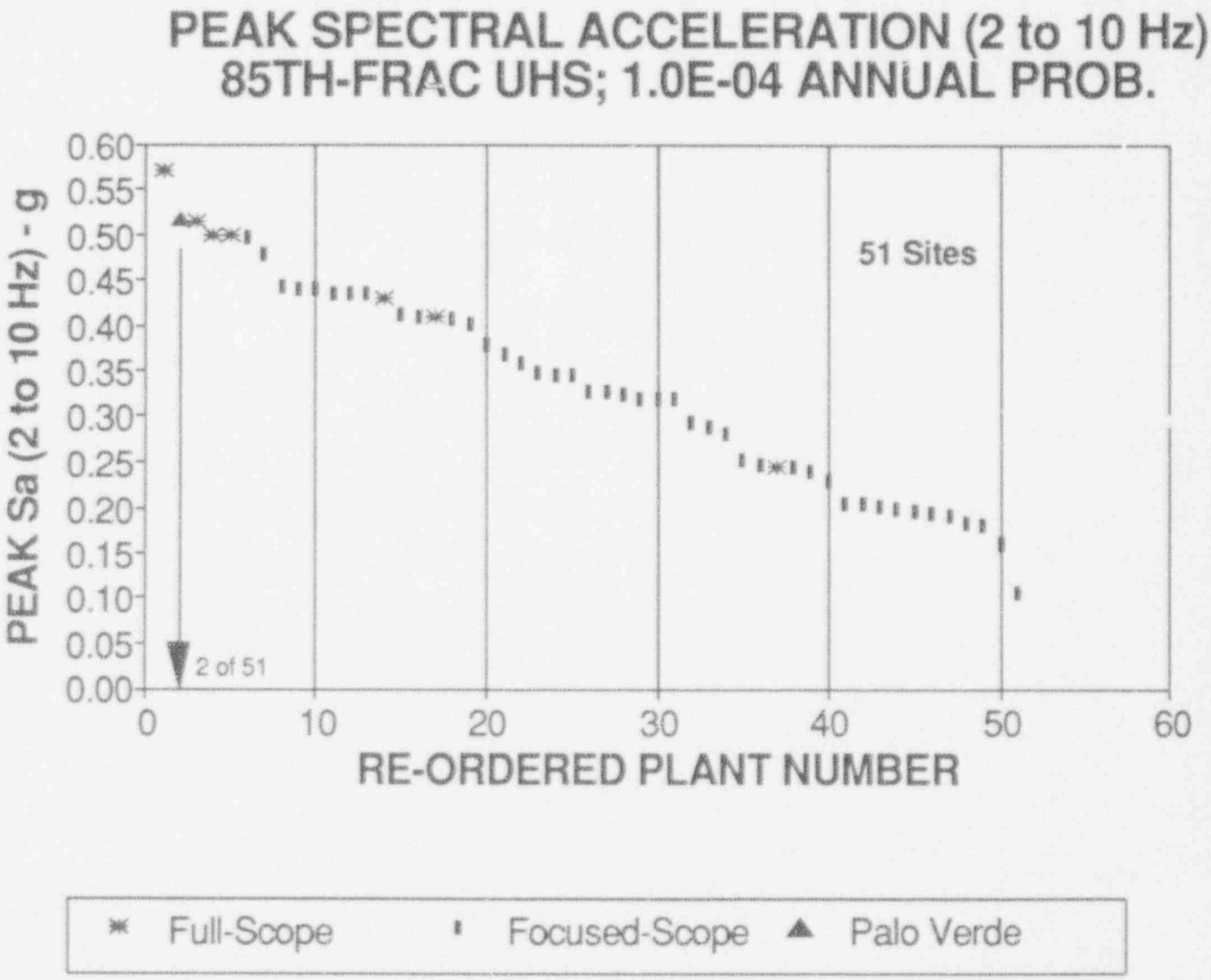


Figure C-15. Comparison of the peak (over the frequency range of 2 to 10 Hz) 10^{-4} 85th-fractile spectral acceleration for the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

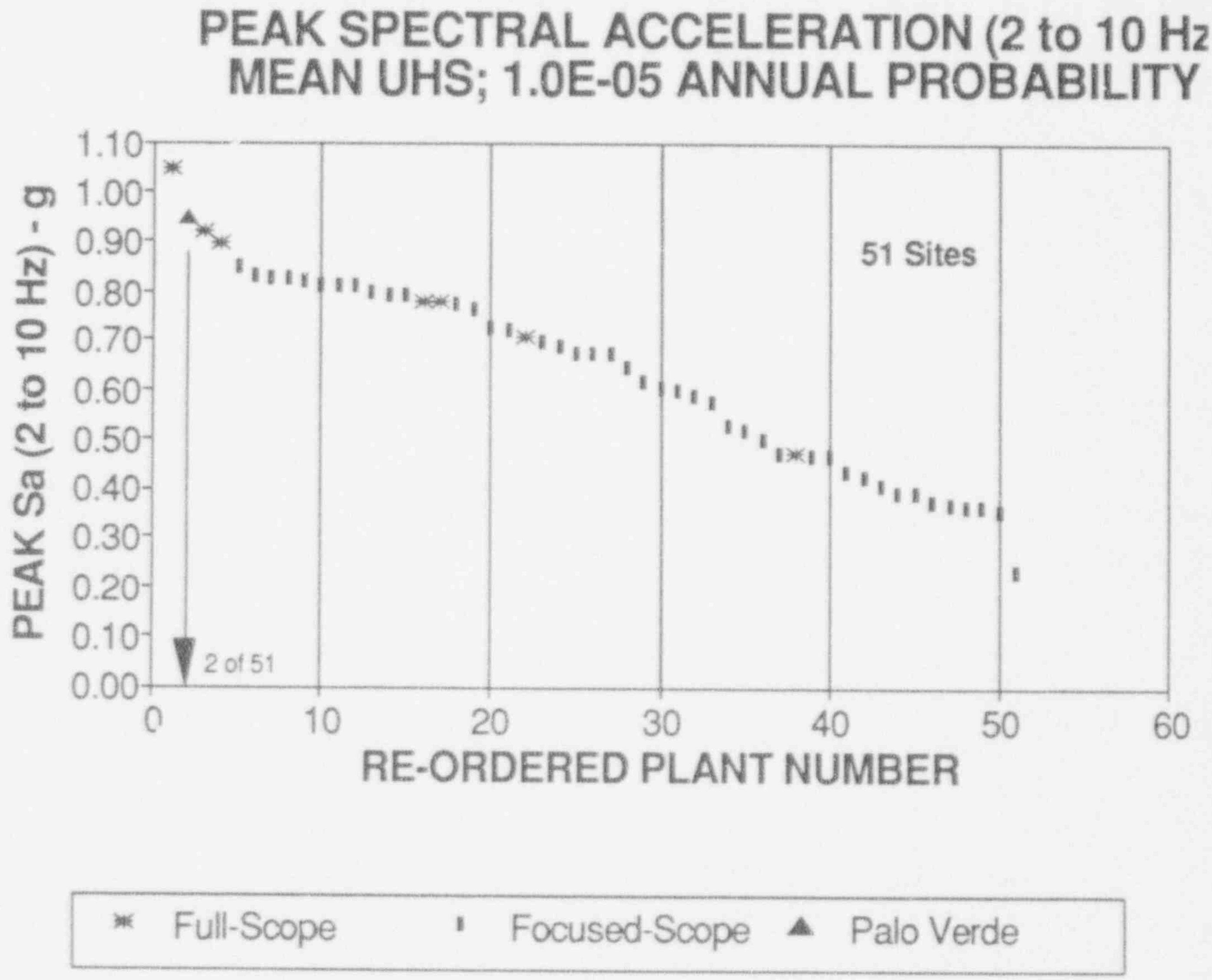


Figure C-16. Comparison of the peak (over the frequency range of 2 to 10 Hz) 10^{-5} mean spectral acceleration for the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

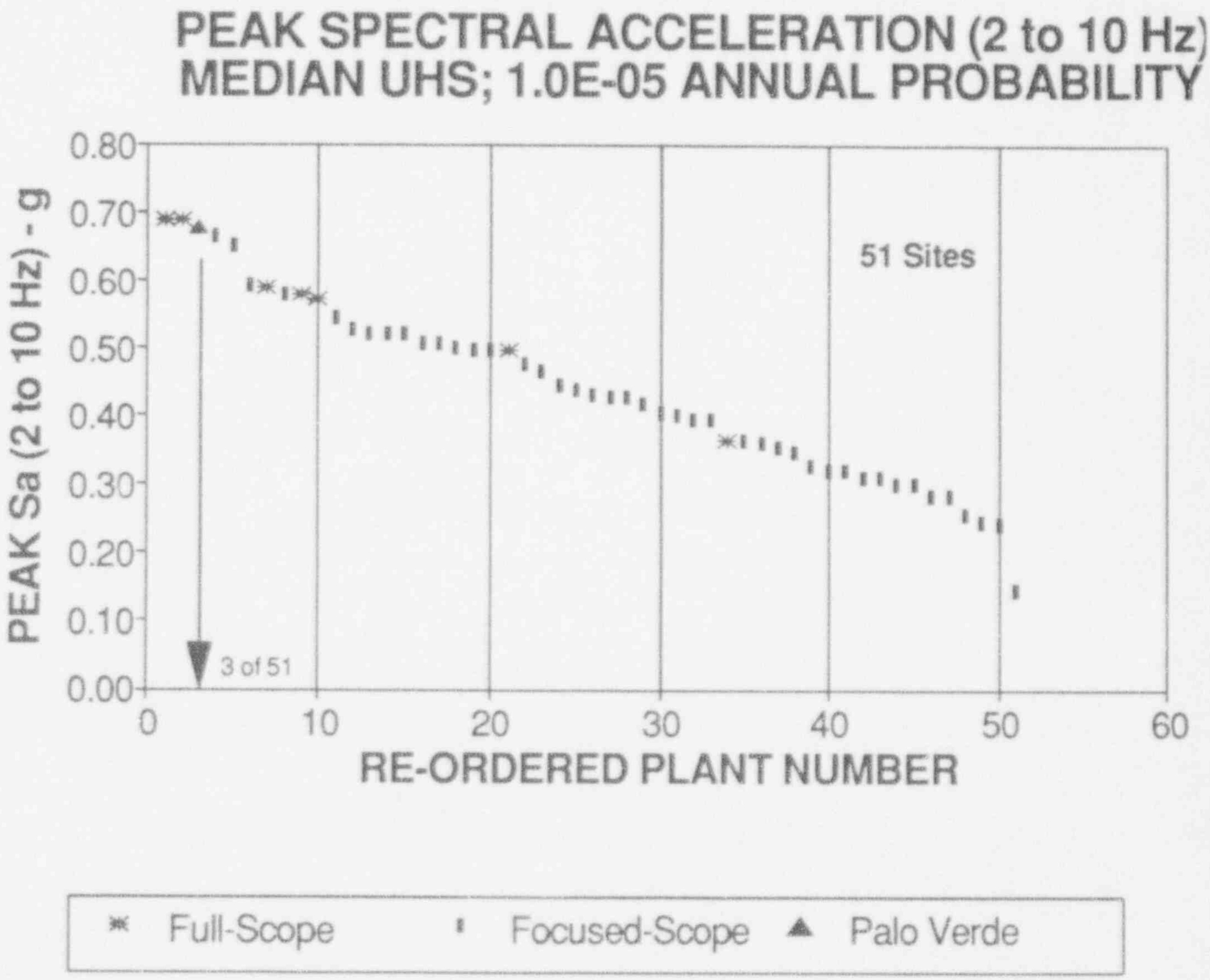


Figure C-17. Comparison of the peak (over the frequency range of 2 to 10 Hz) 10^{-5} median spectral acceleration for the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

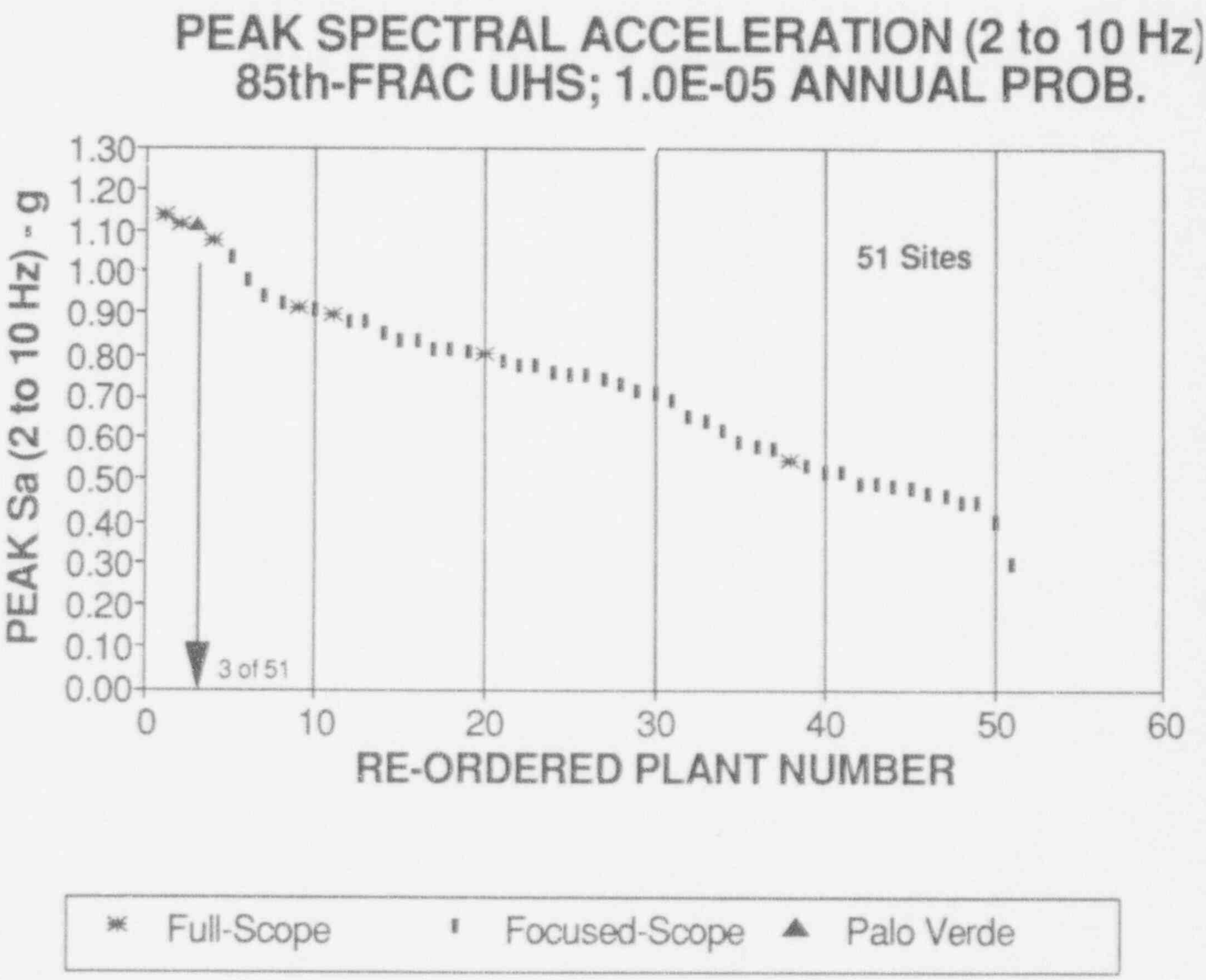


Figure C-18. Comparison of the peak (over the frequency range of 2 to 10 Hz) 10^{-5} 85th-fractile spectral acceleration for the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

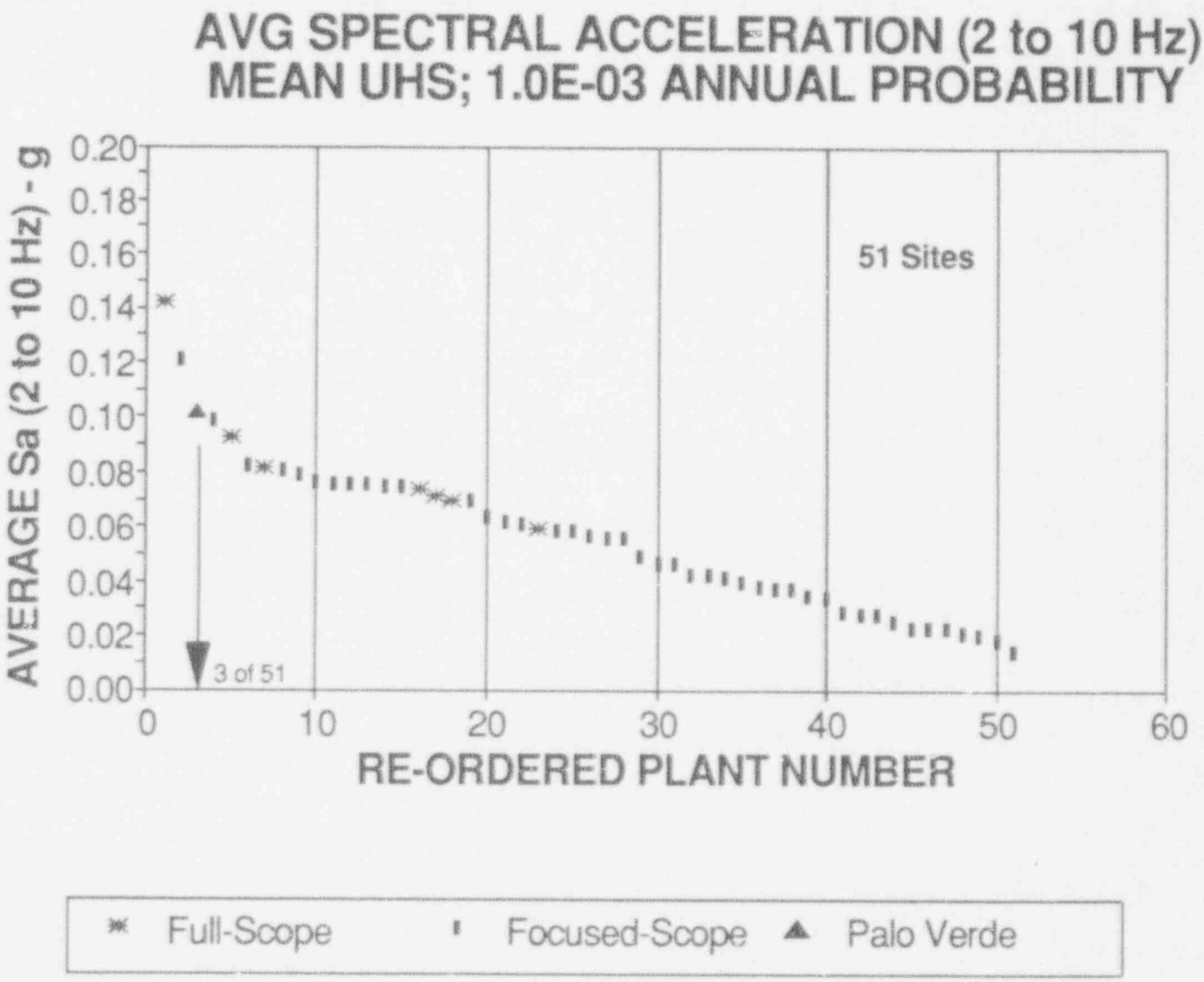


Figure C-19. Comparison of the average (over the frequency range of 2 to 10 Hz) 10^{-3} mean spectral acceleration for the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

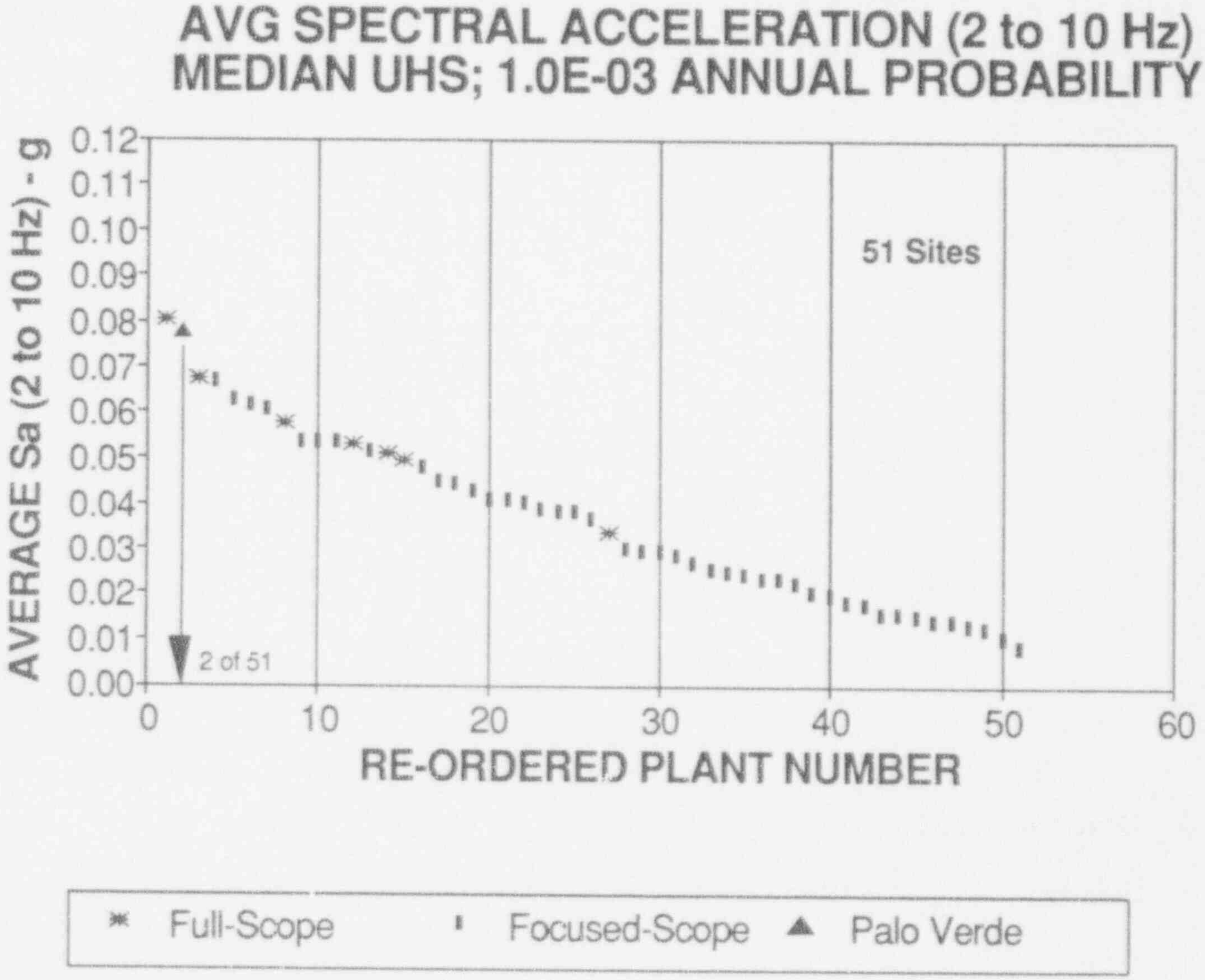


Figure C-20. Comparison of the average (over the frequency range of 2 to 10 Hz) 10^{-3} median spectral acceleration for the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

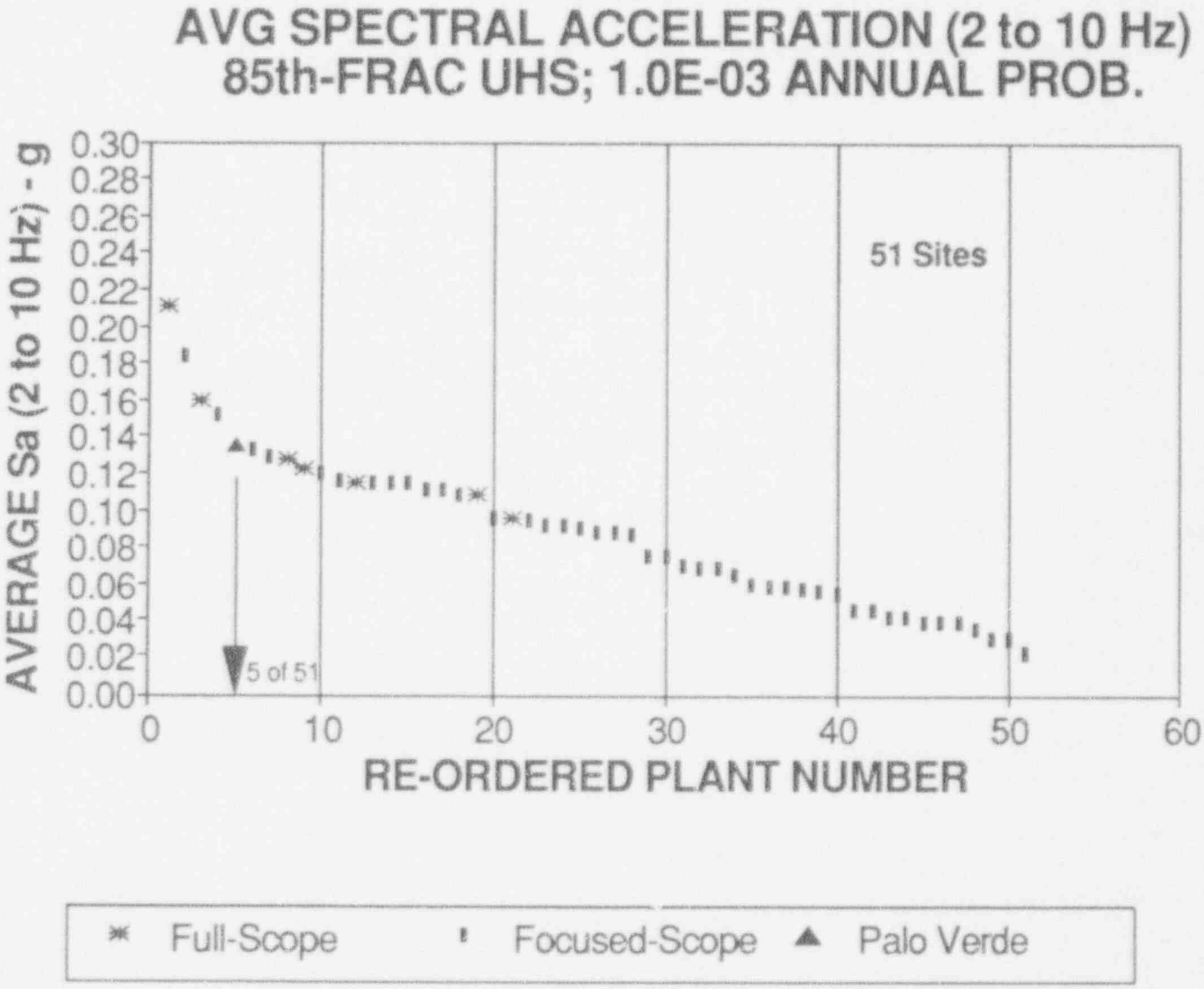


Figure C-21. Comparison of the average (over the frequency range of 2 to 10 Hz) 10^{-3} 85th-fractile spectral acceleration for the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

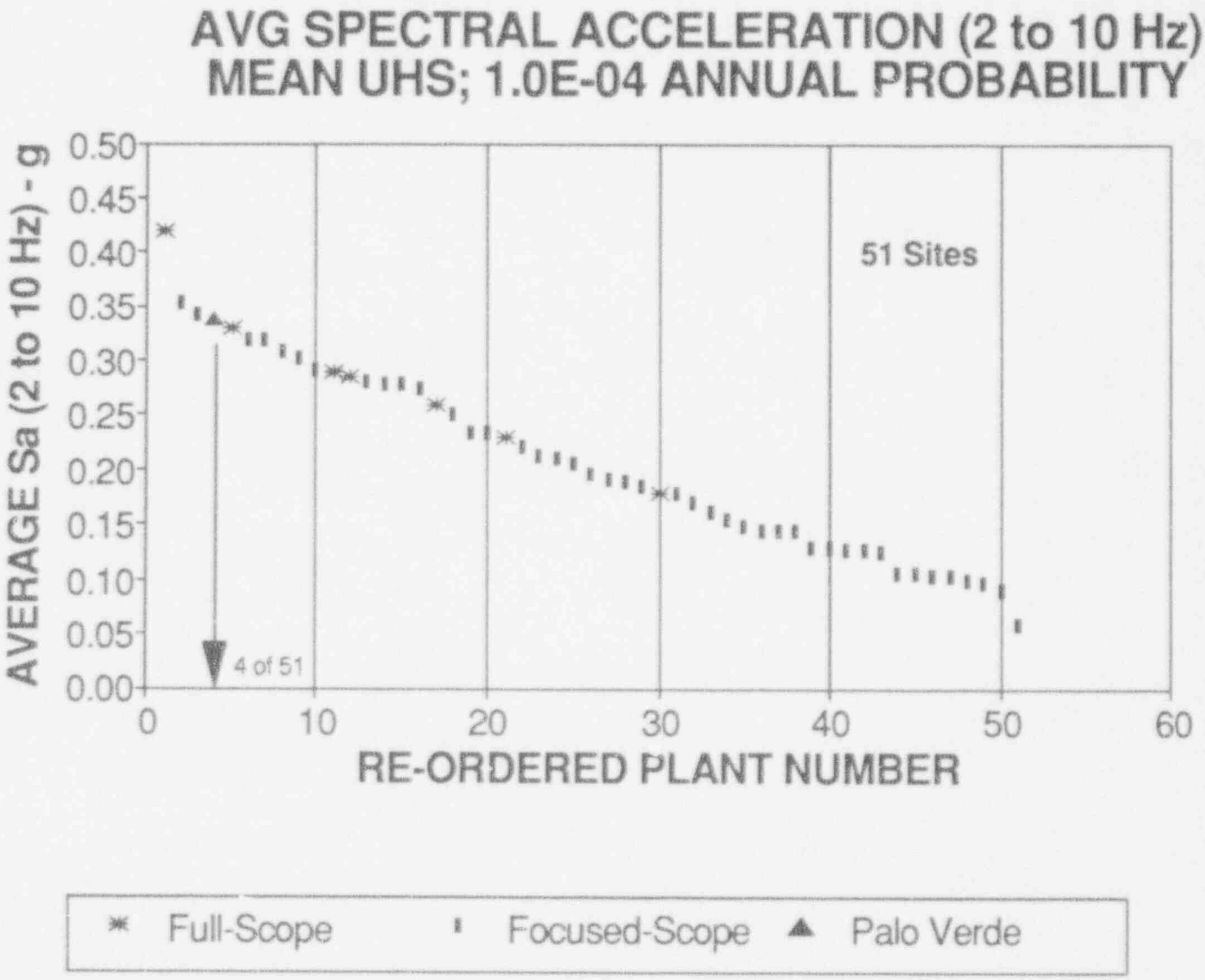


Figure C-22. Comparison of the average (over the frequency range of 2 to 10 Hz) 10^{-4} mean spectral acceleration for the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

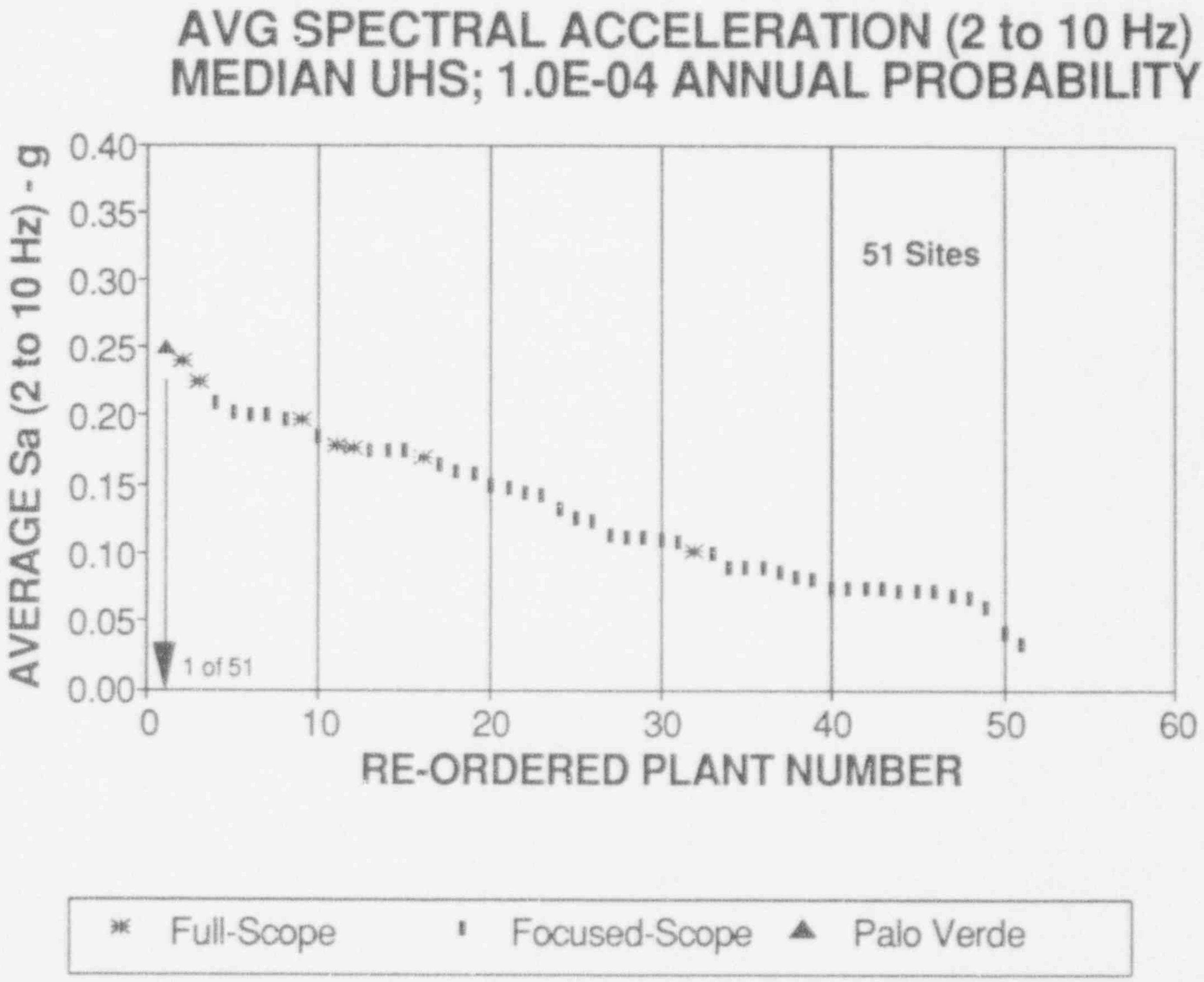


Figure C-23. Comparison of the average (over the frequency range of 2 to 10 Hz) 10^{-4} median spectral acceleration for the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

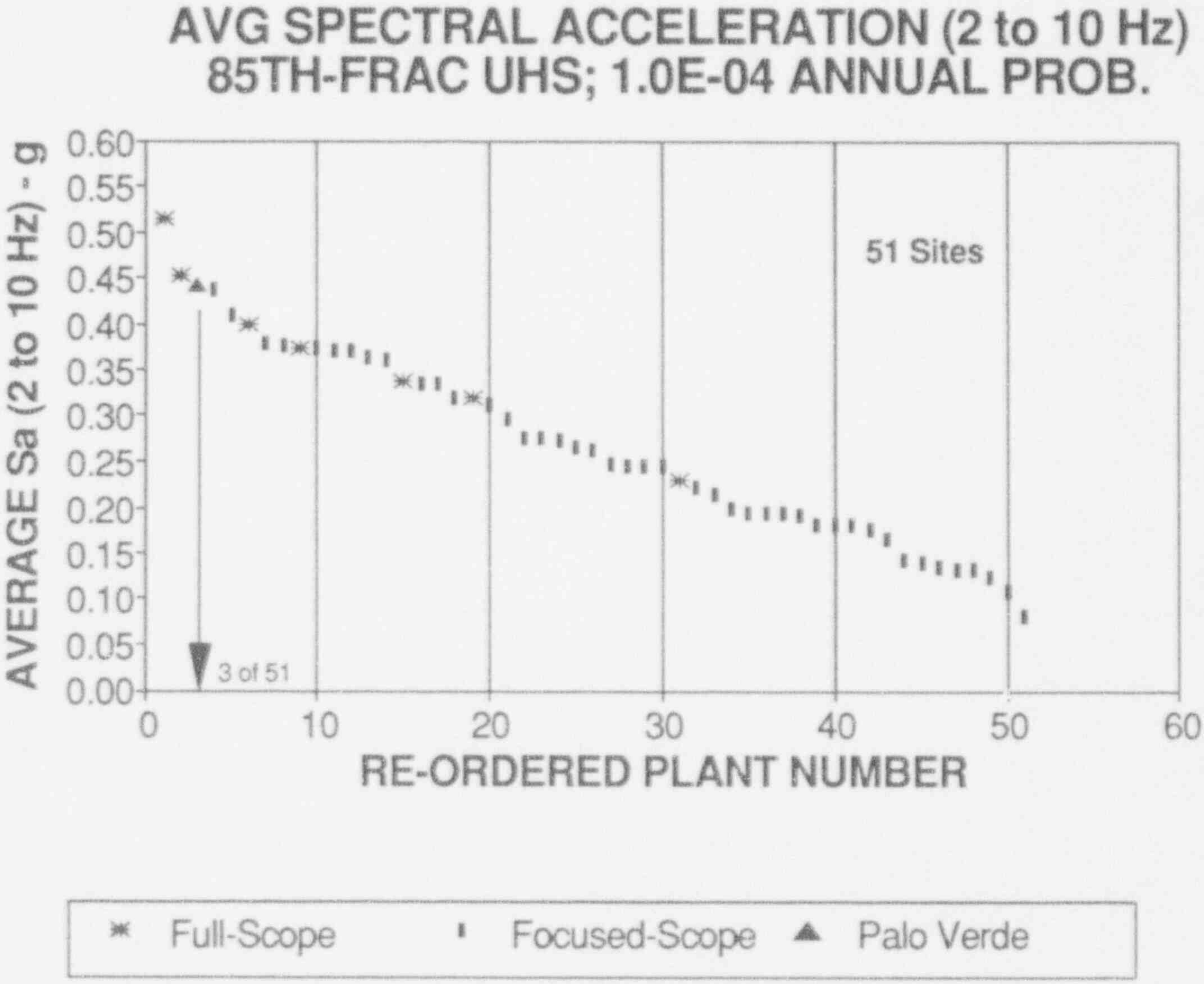


Figure C-24. Comparison of the average (over the frequency range of 2 to 10 Hz) 10^{-4} 85th-fractile spectral acceleration for the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

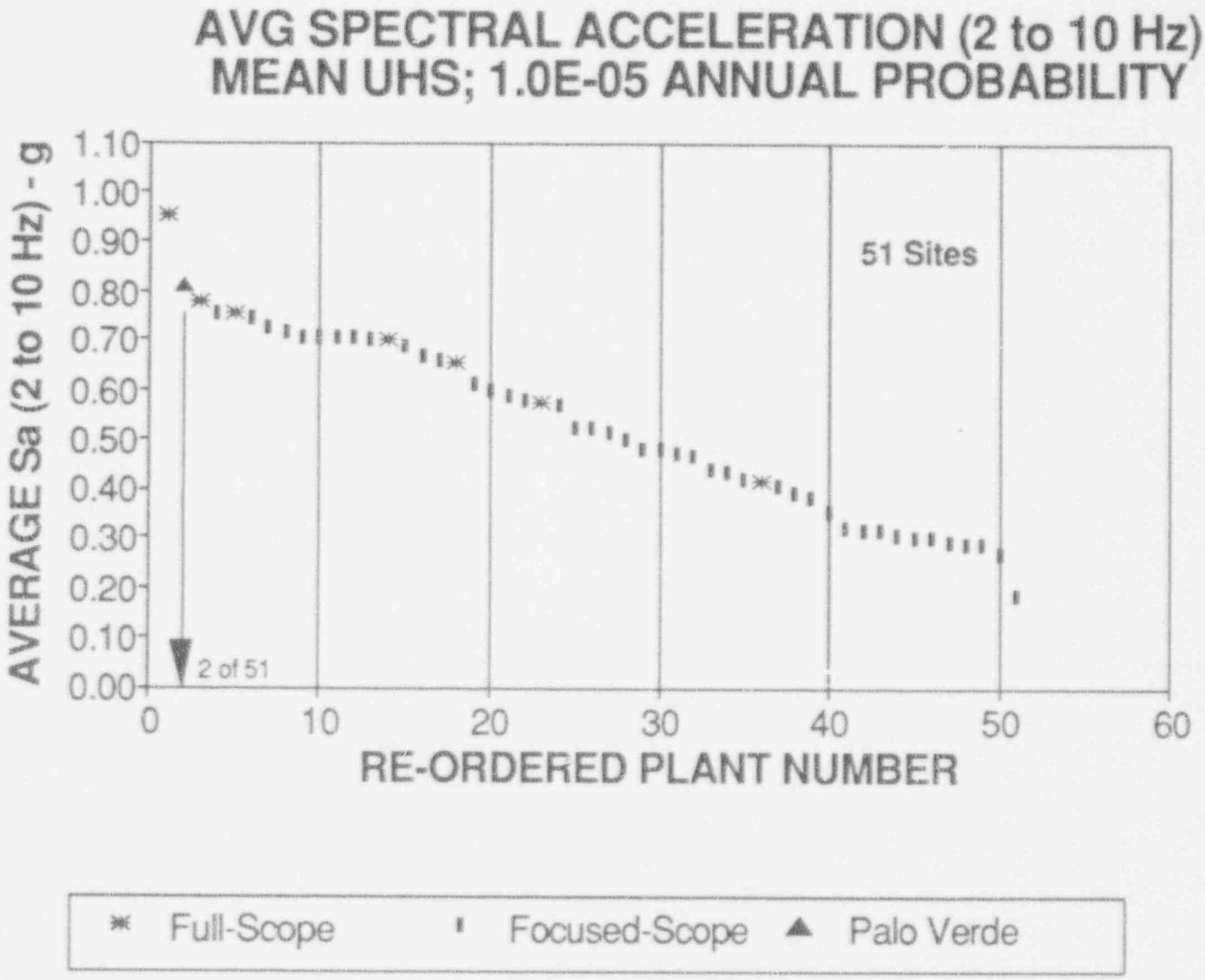


Figure C-25. Comparison of the average (over the frequency range of 2 to 10 Hz) 10^{-5} mean spectral acceleration for the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

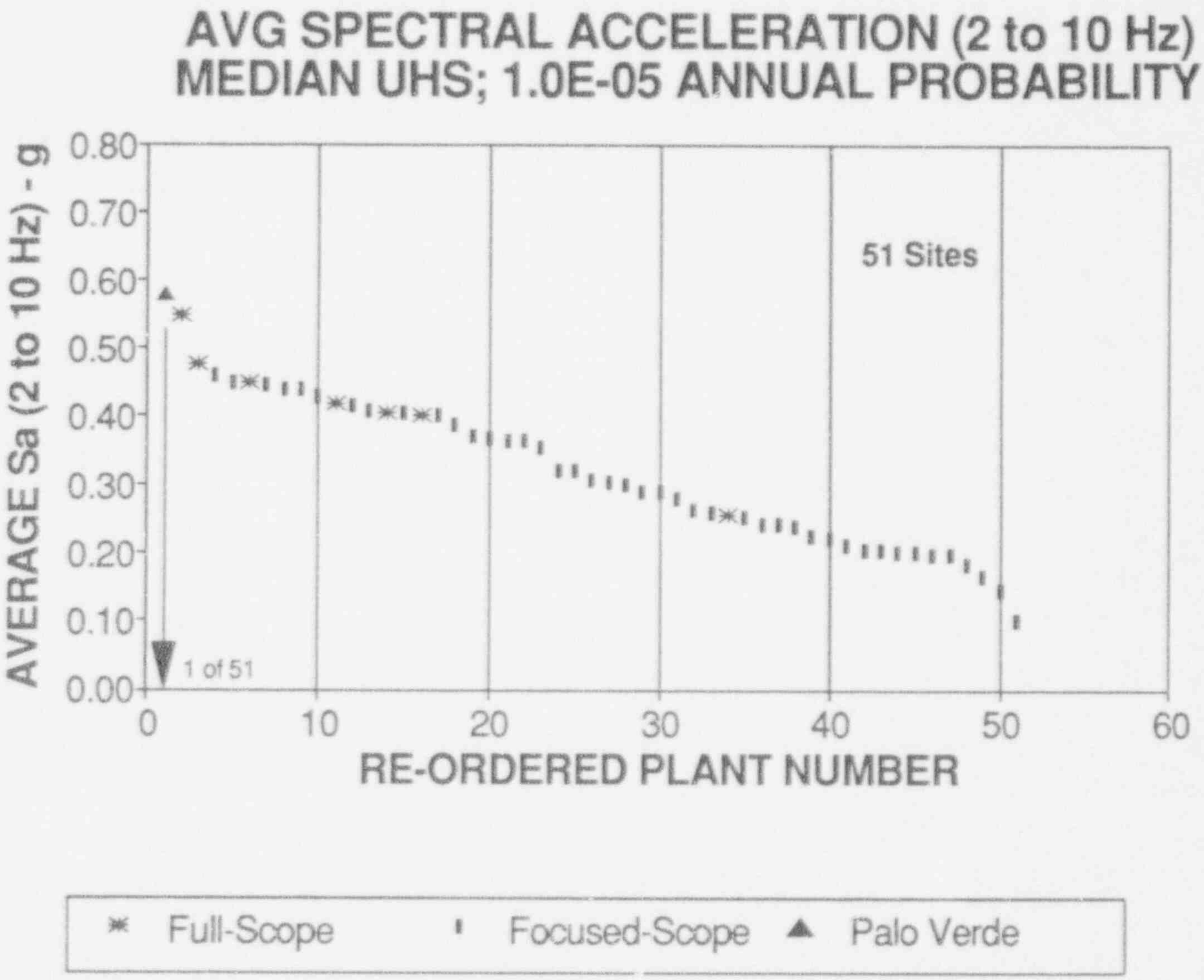


Figure C-26. Comparison of the average (over the frequency range of 2 to 10 Hz) 10^{-5} median spectral acceleration for the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

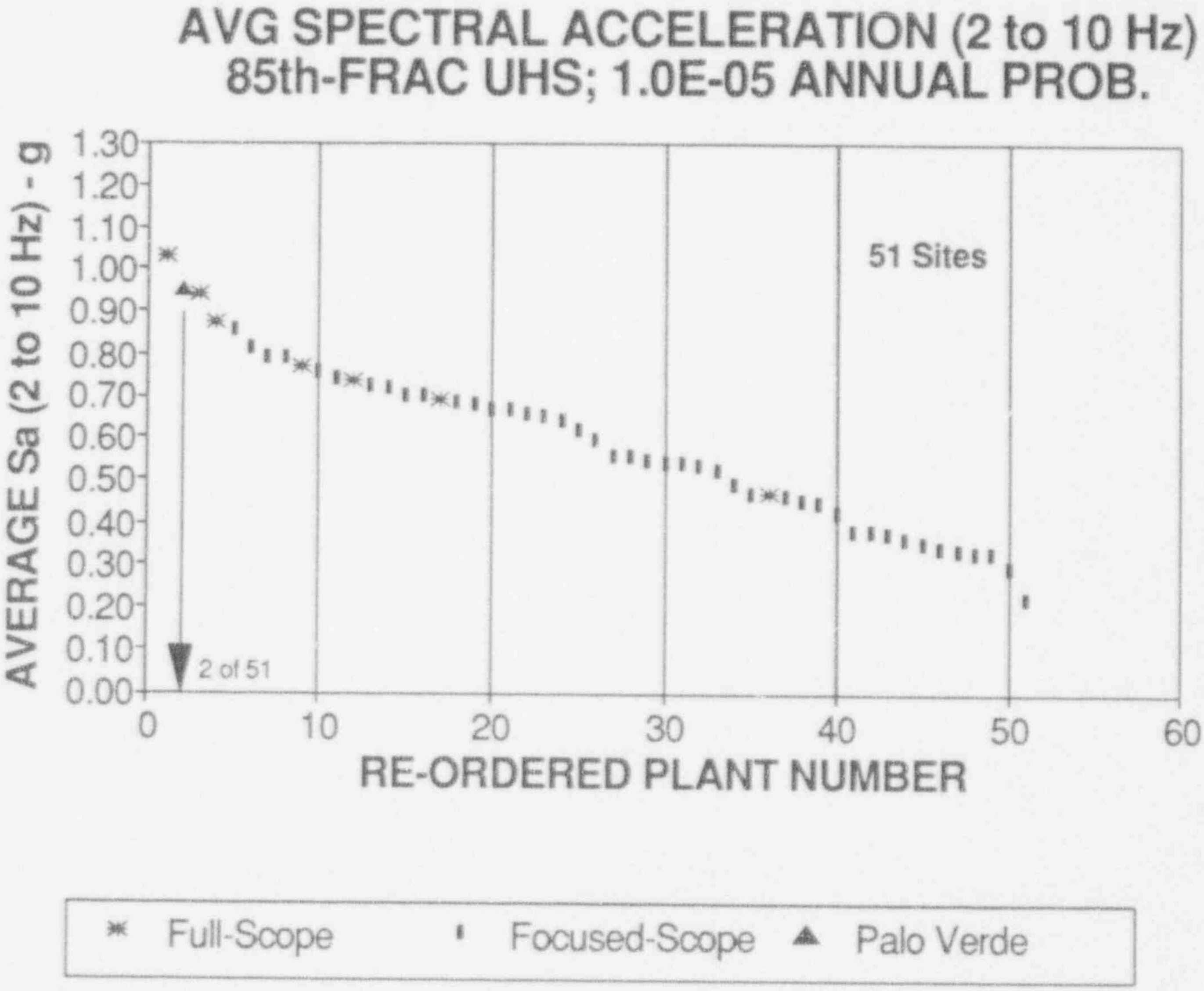


Figure C-27. Comparison of the average (over the frequency range of 2 to 10 Hz) 10^{-5} 85th-fractile spectral acceleration for the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g plants in the central and eastern U.S.

Appendix D

COMPARISONS OF EXCEEDANCE PROBABILITIES INCLUDING 0.5G PLANTS

This appendix presents results of probabilities of exceeding the NUREG/CR-0098 median, 5%-damped spectrum for both 0.3g and 0.5g CEUS plants, so that comparison of hazard results may be developed which include the 0.5g plants. The comparisons are useful because they demonstrate that the seismic hazard at PVNGS is unlike (i.e., lower than) the seismic hazard for plants assigned to the 0.5g bin.

Exceedance probabilities are provided for the Palo Verde site and for 52 nuclear power plant locations in the central and eastern United States. The exceedance probabilities are determined as outlined in Section 4, and are computed for the reference NUREG/CR-0098 spectrum anchored to the PGA level of 0.3g. Scalar measures of exceedance probabilities consist of composite probability of exceedance, alternate composite probability of exceedance, peak exceedance probability over the vibrational-frequency range of 2.0 to 10.0 Hz, and exceedance probability averaged over the same frequency range (see Section 4 for more-detailed definitions of these measures). In all cases, comparisons are provided for the mean, median, and 85th-fractile hazards.

Hazard results for the 52 central and eastern U.S. sites are based on the EPRI methodology. The 52 sites are comprised of two 0.5g plants (i.e., those plant listed in NUREG-1407 as having committed to performing a seismic PRA). The other 50 plants are, as presented in Appendices A, B and C, the 0.3g full-scope and focused-scope plants for which EPRI hazard results have been obtained; seven of these plants are full-scope plants, and the remaining 43 are focused-scope plants.

Figures D-1 to D-3 present plots of ordered composite exceedance probability; Figures D-4 to D-6 present plots of ordered alternate-composite exeedance probability; Figures D-7 to D-9 and Figures D-10 to D-12 present, respectively, plots of ordered peak and averaged exceedance probability over the vibrational frequency range of 2 to 10 Hz.

The plots presented in this appendix support the comparisons and observations made in Section 5 of this report, and provide the basis for developing the plant rankings summary indicated in Tables 5-3 and plant-by-plant comparisons in Tables 5-4 to 5-15.

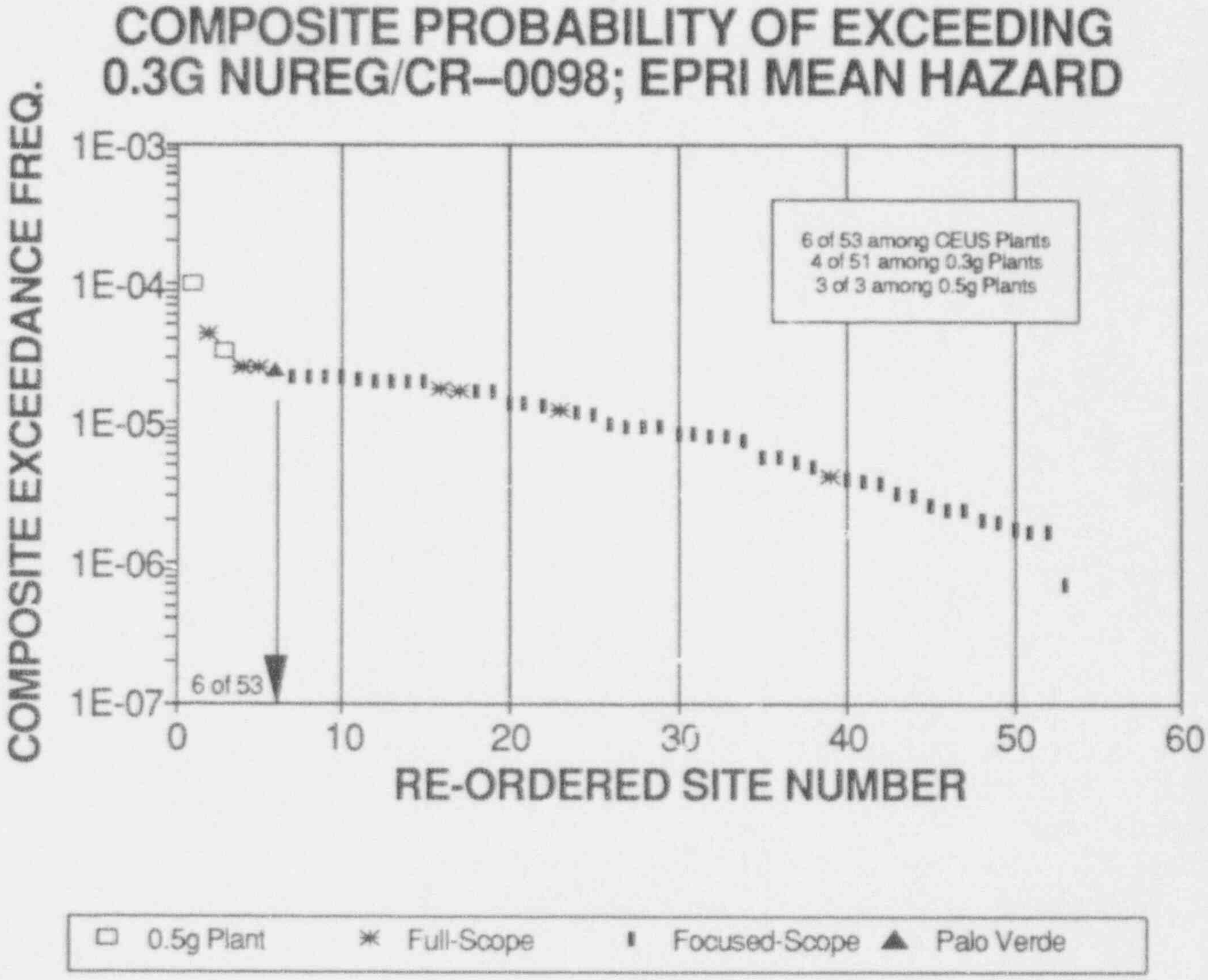


Figure D-1. Comparison of the composite mean probability of exceeding the NUREG/CR-0098 median, 5%-damped spectrum anchored to 0.3g: comparison of results for the the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g CEUS plants and two 0.5g CEUS plants.

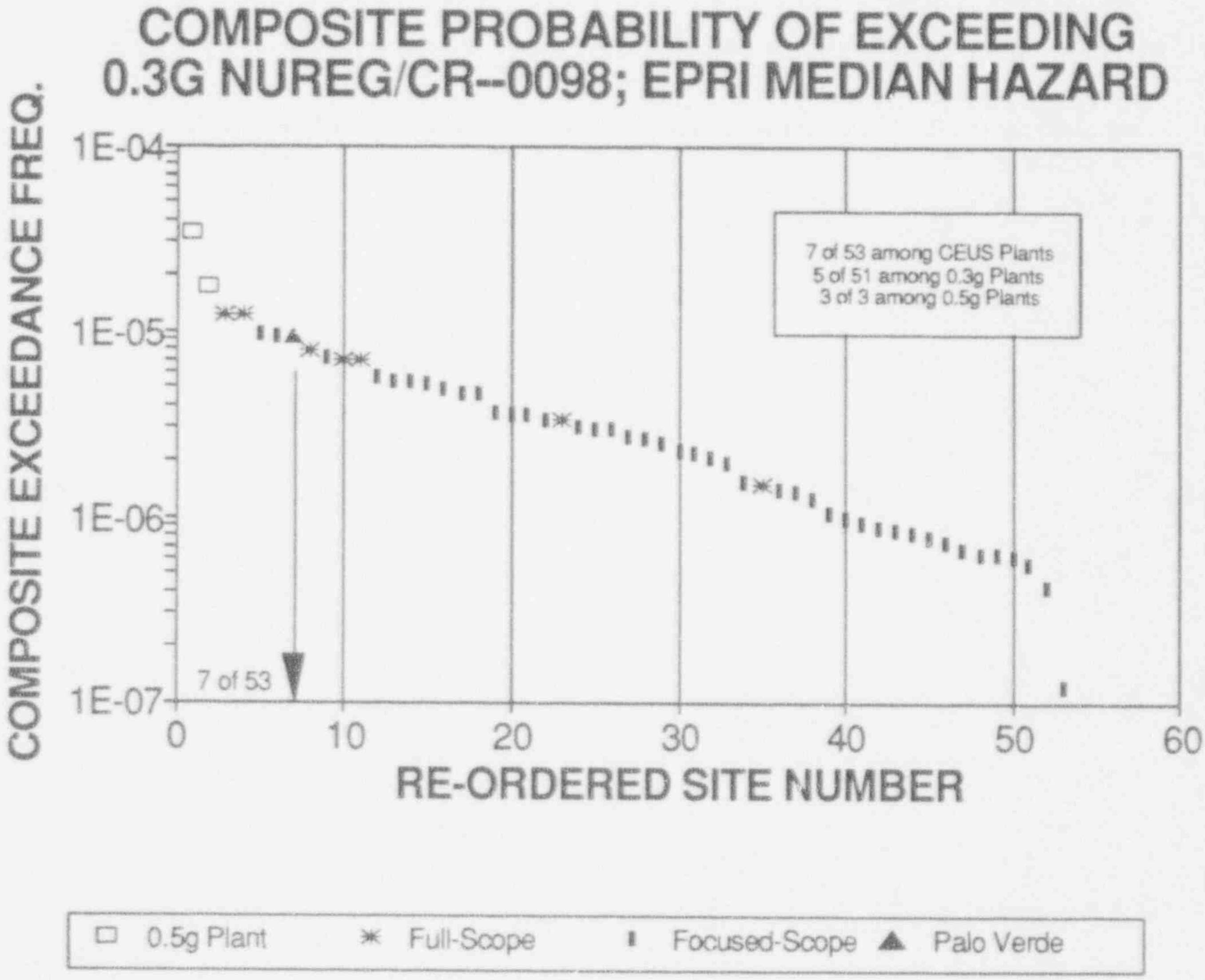


Figure D-2. Comparison of the composite median probability of exceeding the NUREG/CR-0098 median, 5%-damped spectrum anchored to 0.3g: comparison of results for the the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g CEUS plants and two 0.5g CEUS plants.

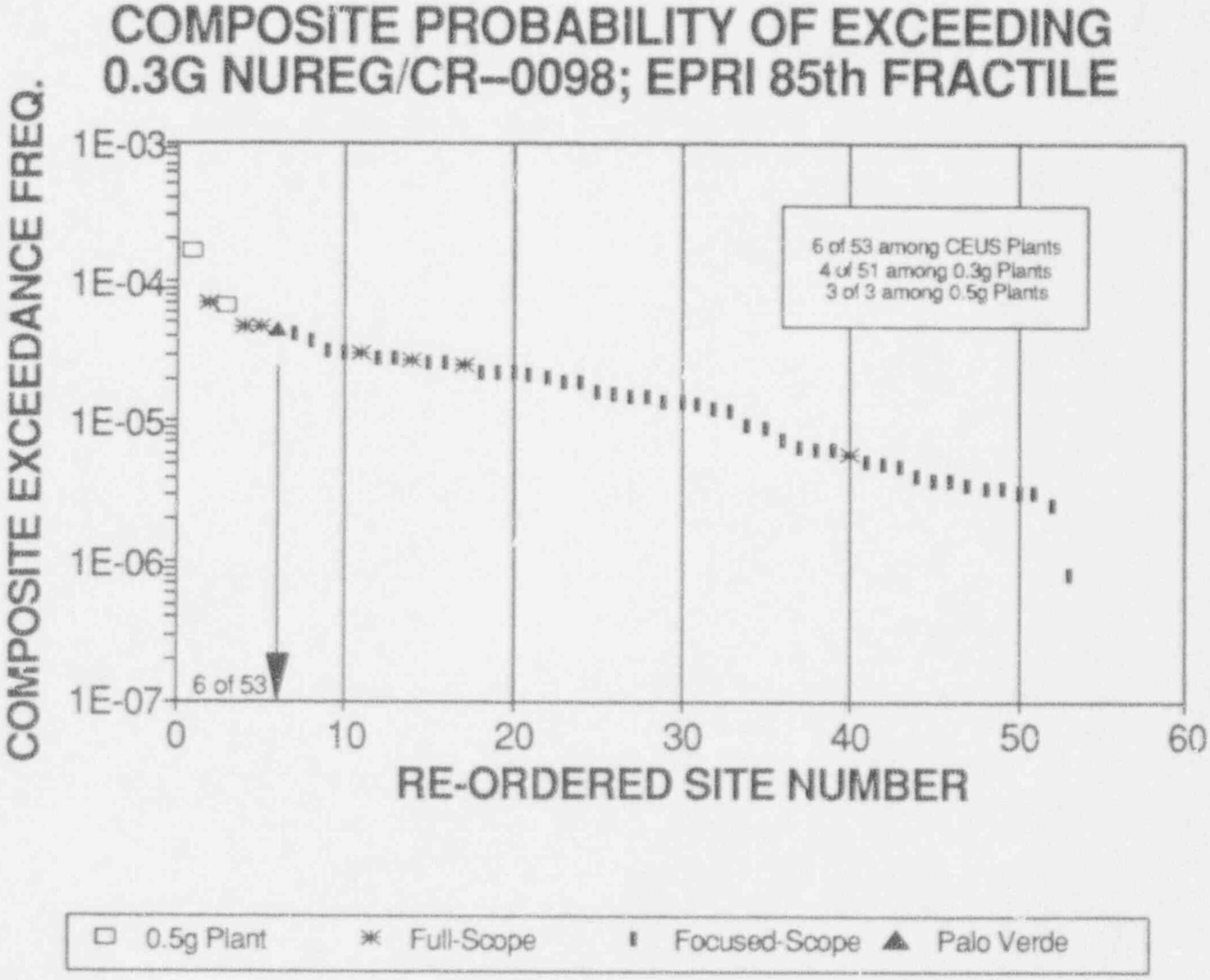


Figure D-3. Comparison of the composite 85th-fractile probability of exceeding the NUREG/CR-0098 median, 5%-damped spectrum anchored to 0.3g: comparison of results for the the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g CEUS plants and two 0.5g CEUS plants.

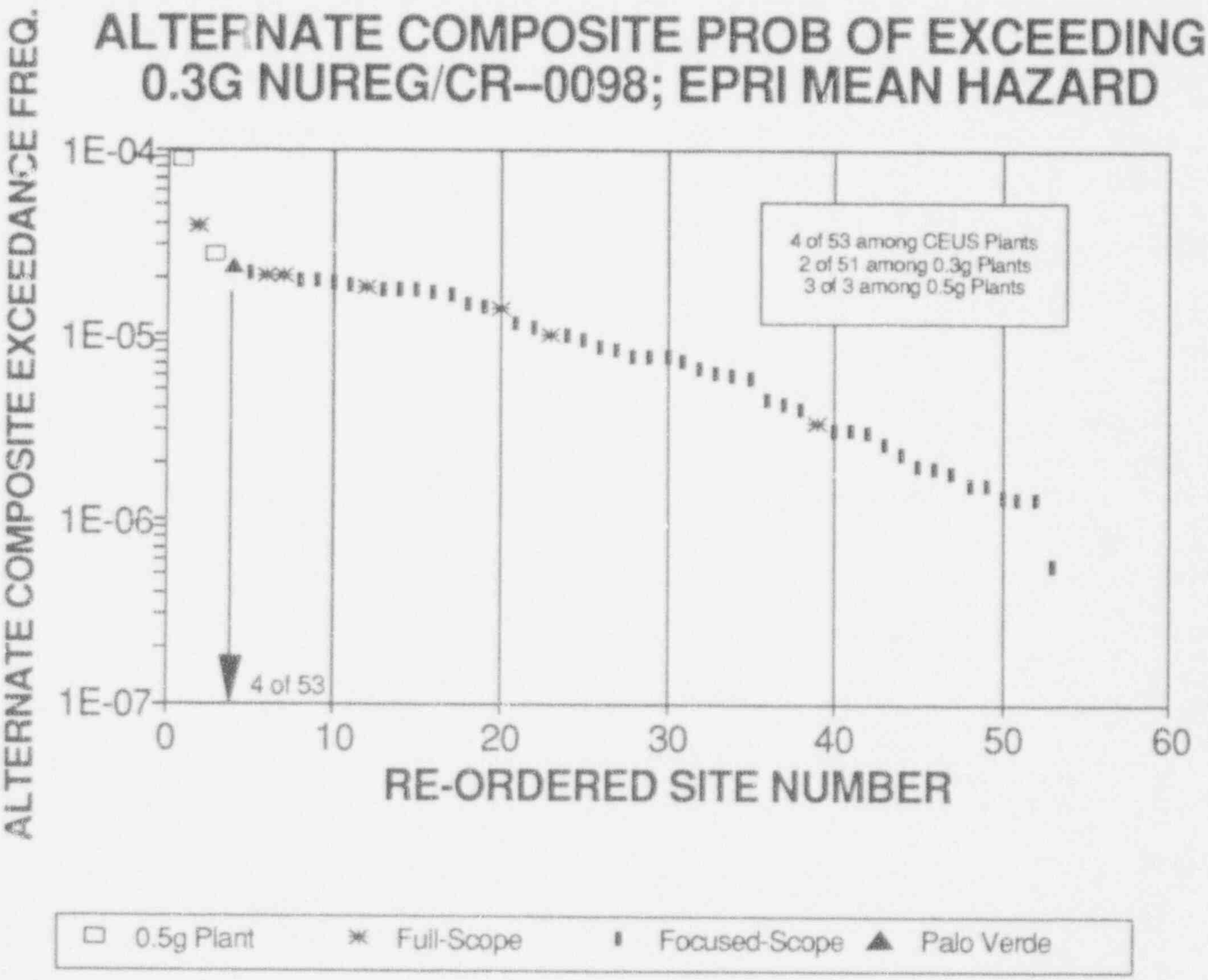


Figure D-4. Comparison of the alternate-composite mean probability of exceeding the NUREG/CR-0098 median, 5%-damped spectrum anchored to 0.3g: comparison of results for the the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g CEUS plants and two 0.5g CEUS plants.

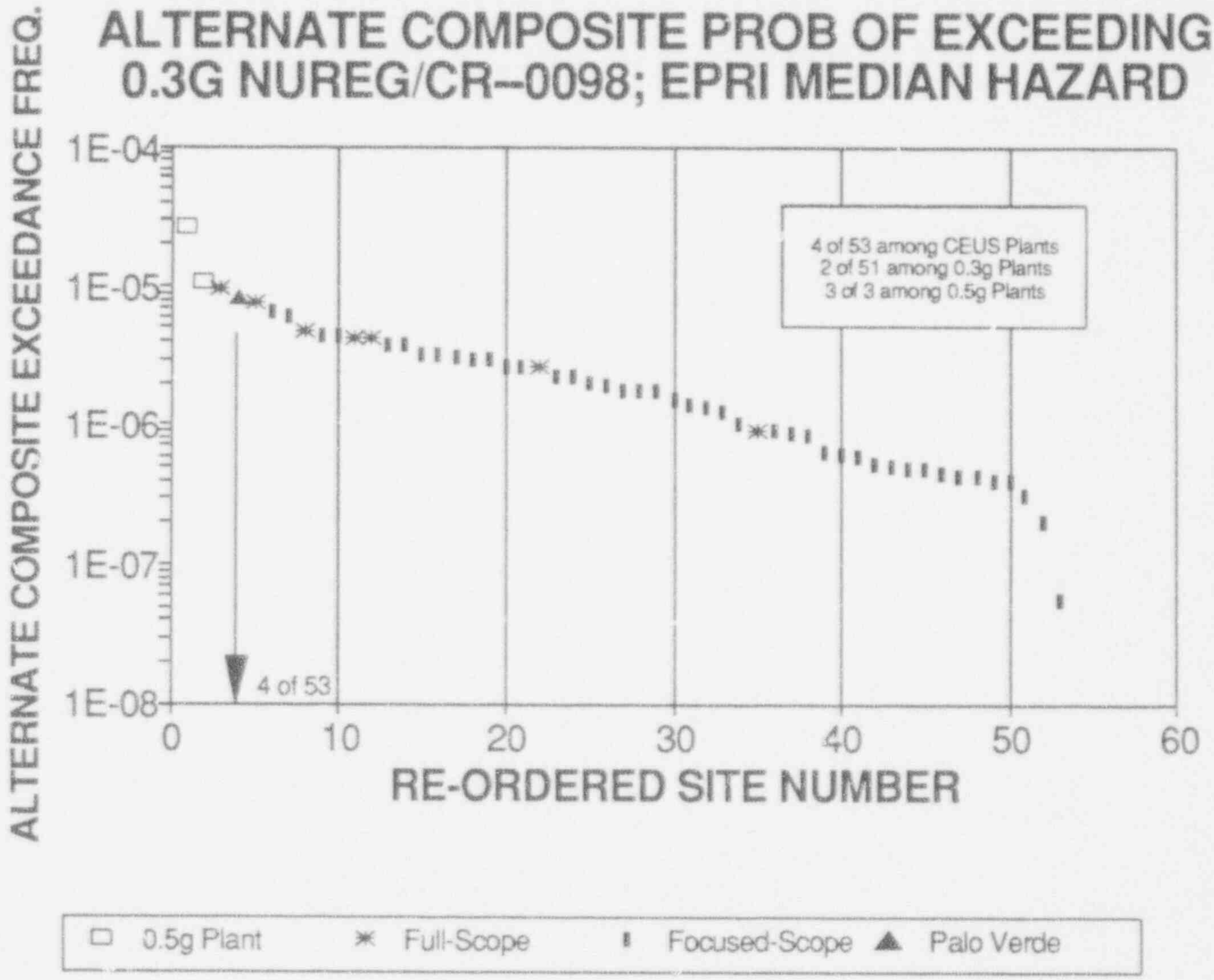


Figure D-5. Comparison of the alternate-composite median probability of exceeding the NUREG/CR-0098 median, 5%-damped spectrum anchored to 0.3g: comparison of results for the the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g CEUS plants and two 0.5g CEUS plants.

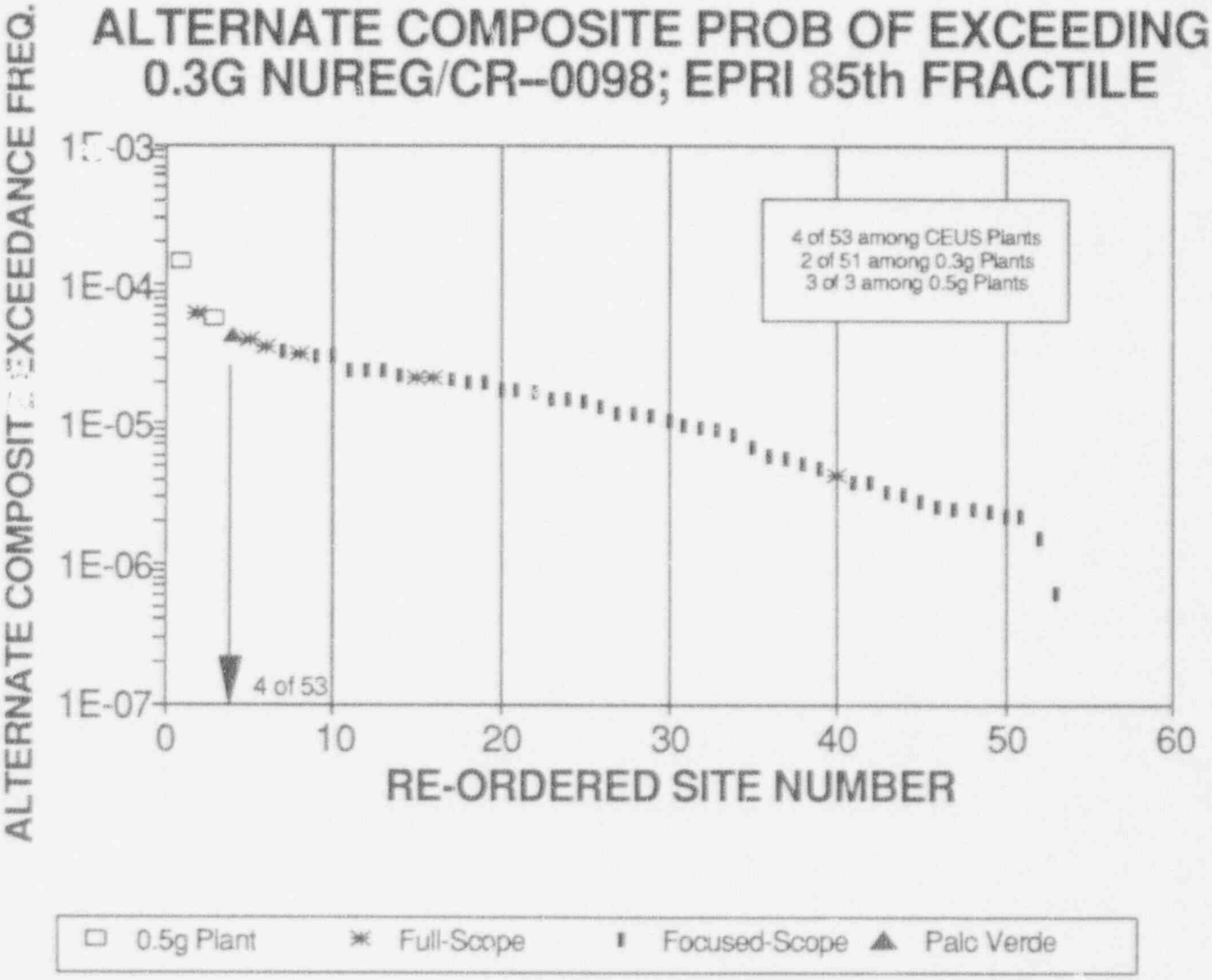


Figure D-6. Comparison of the alternate-composite 85th-fractile probability of exceeding the NUREG/CR-0098 median, 5%-damped spectrum anchored to 0.3g: comparison of results for the the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g CEUS plants and two 0.5g CEUS plants.

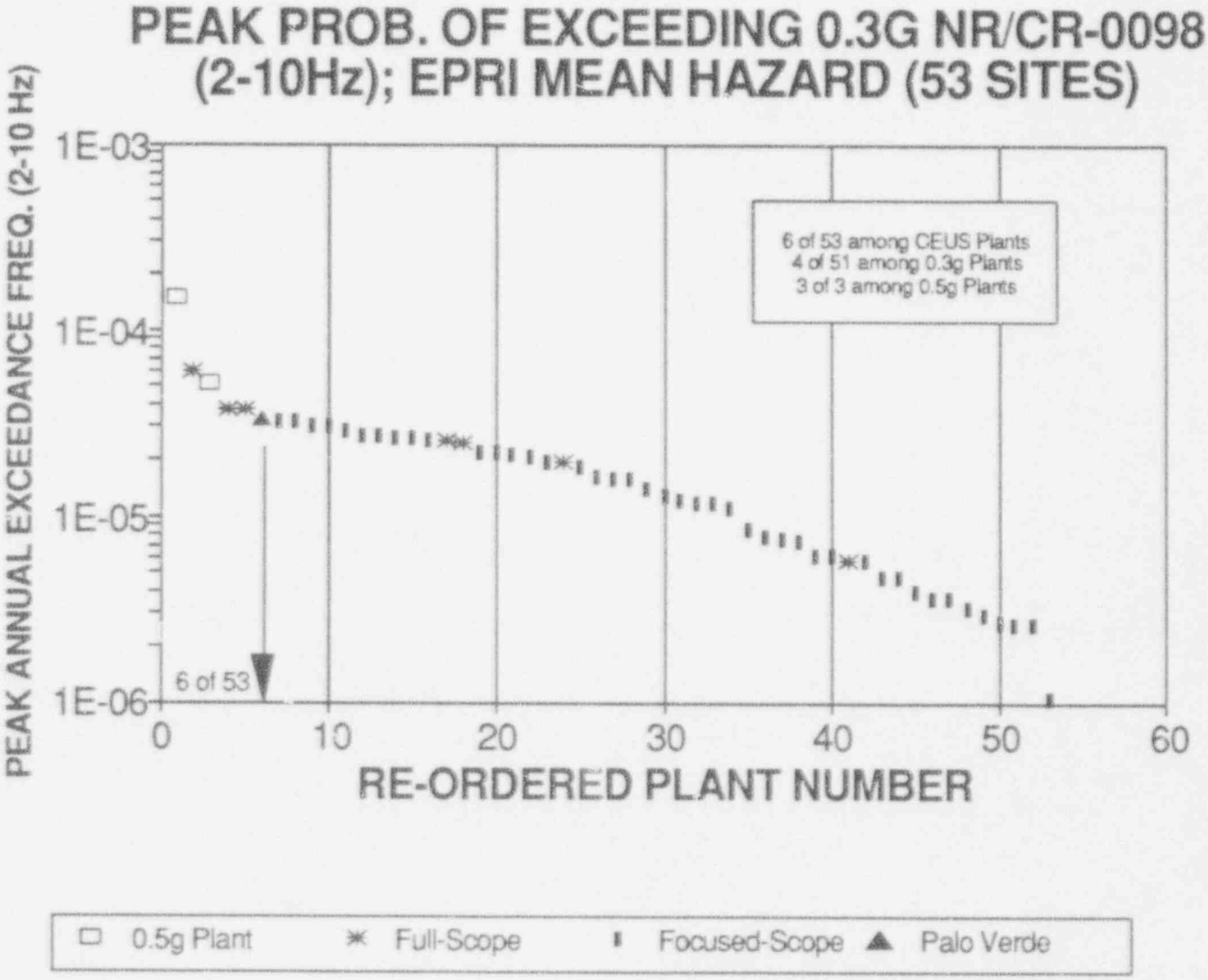


Figure D-7. Comparison of the peak (over the frequency range of 2 to 10 Hz) mean probability of exceeding the NUREG/CR-0098 median, 5%-damped spectrum anchored to 0.3g: comparison of results for the the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g CEUS plants and two 0.5g CEUS plants.

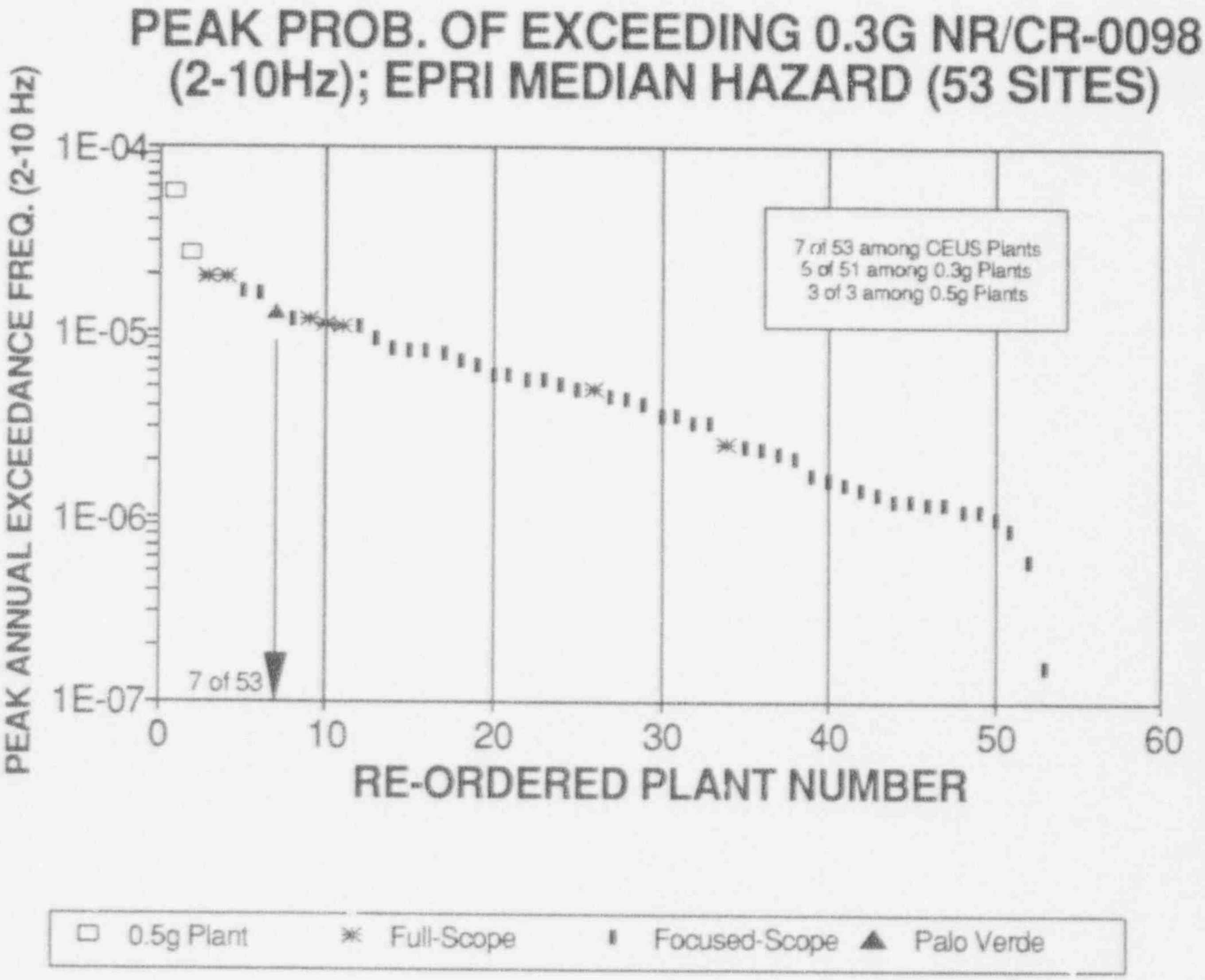


Figure D-8. Comparison of the peak (over the frequency range of 2 to 10 Hz) median probability of exceeding the NUREG/CR-0098 median, 5%-damped spectrum anchored to 0.3g: comparison of results for the the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g CEUS plants and two 0.5g CEUS plants.

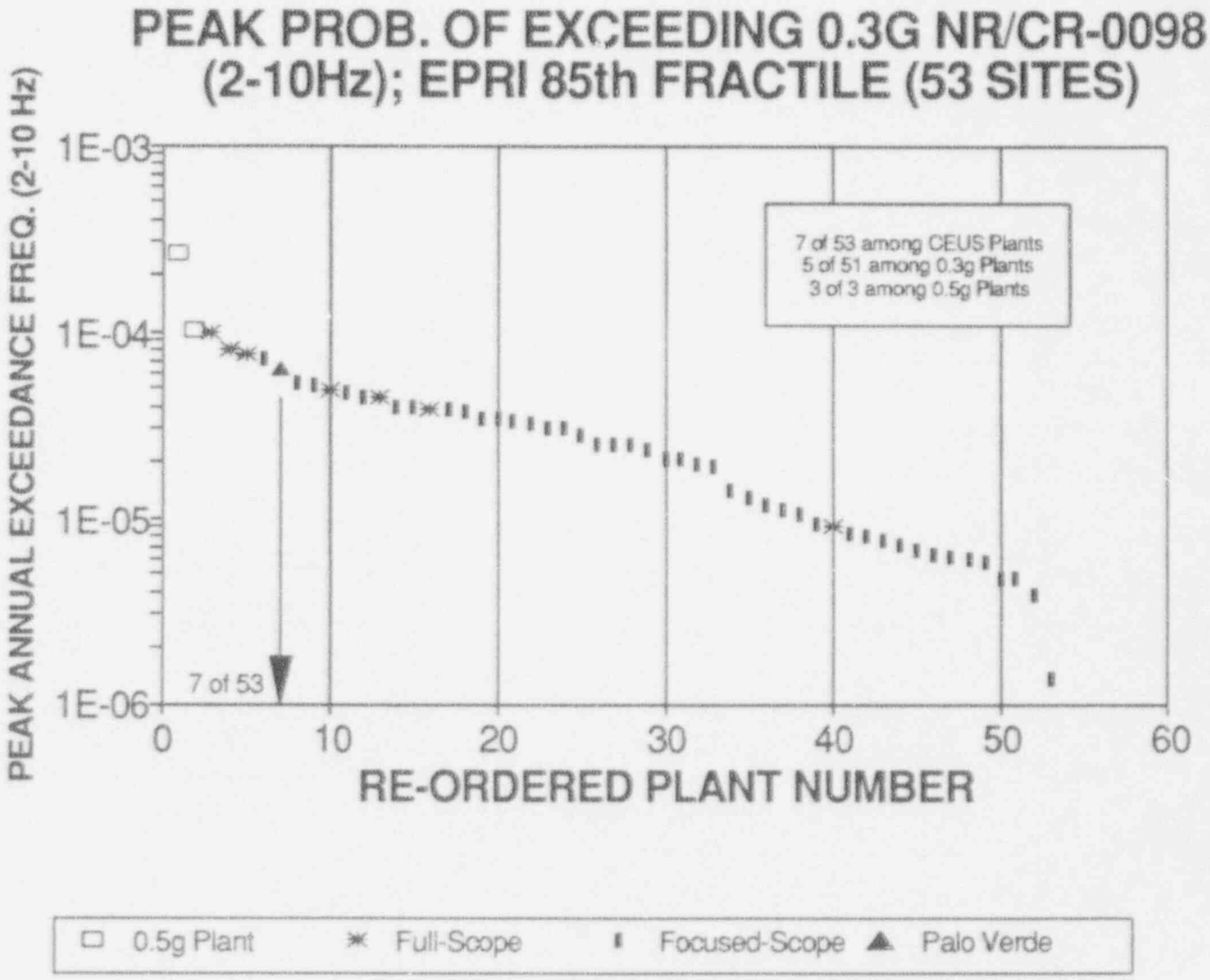


Figure D-9. Comparison of the peak (over the frequency range of 2 to 10 Hz) 85th-fractile probability of exceeding the NUREG/CR-0098 median, 5%-damped spectrum anchored to 0.3g: comparison of results for the the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g CEUS plants and two 0.5g CEUS plants.

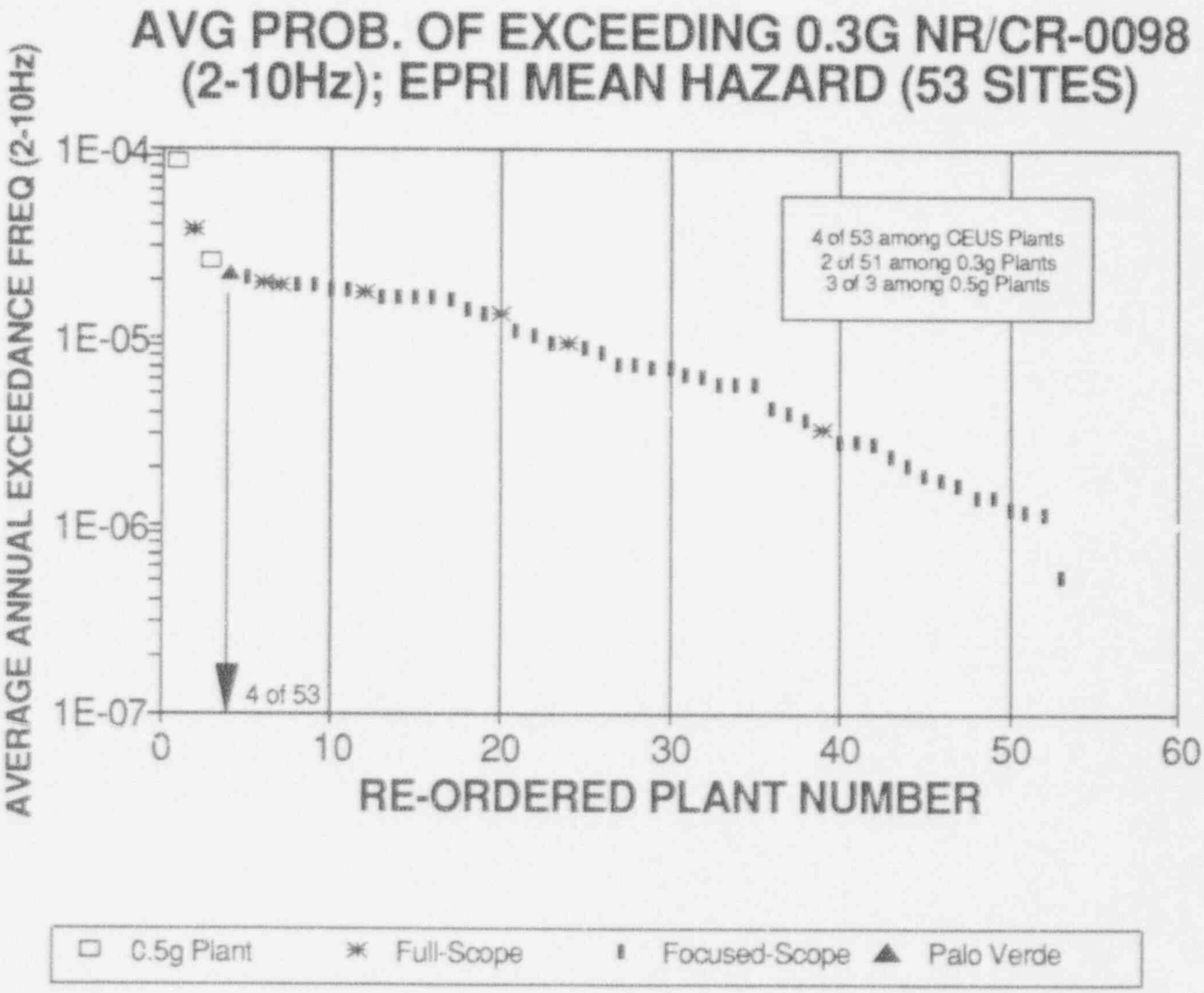


Figure D-10. Comparison of the average (over the frequency range of 2 to 10 Hz) mean probability of exceeding the NUREG/CR–0098 median, 5%-damped spectrum anchored to 0.3g: comparison of results for the the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g CEUS plants and two 0.5g CEUS plants.

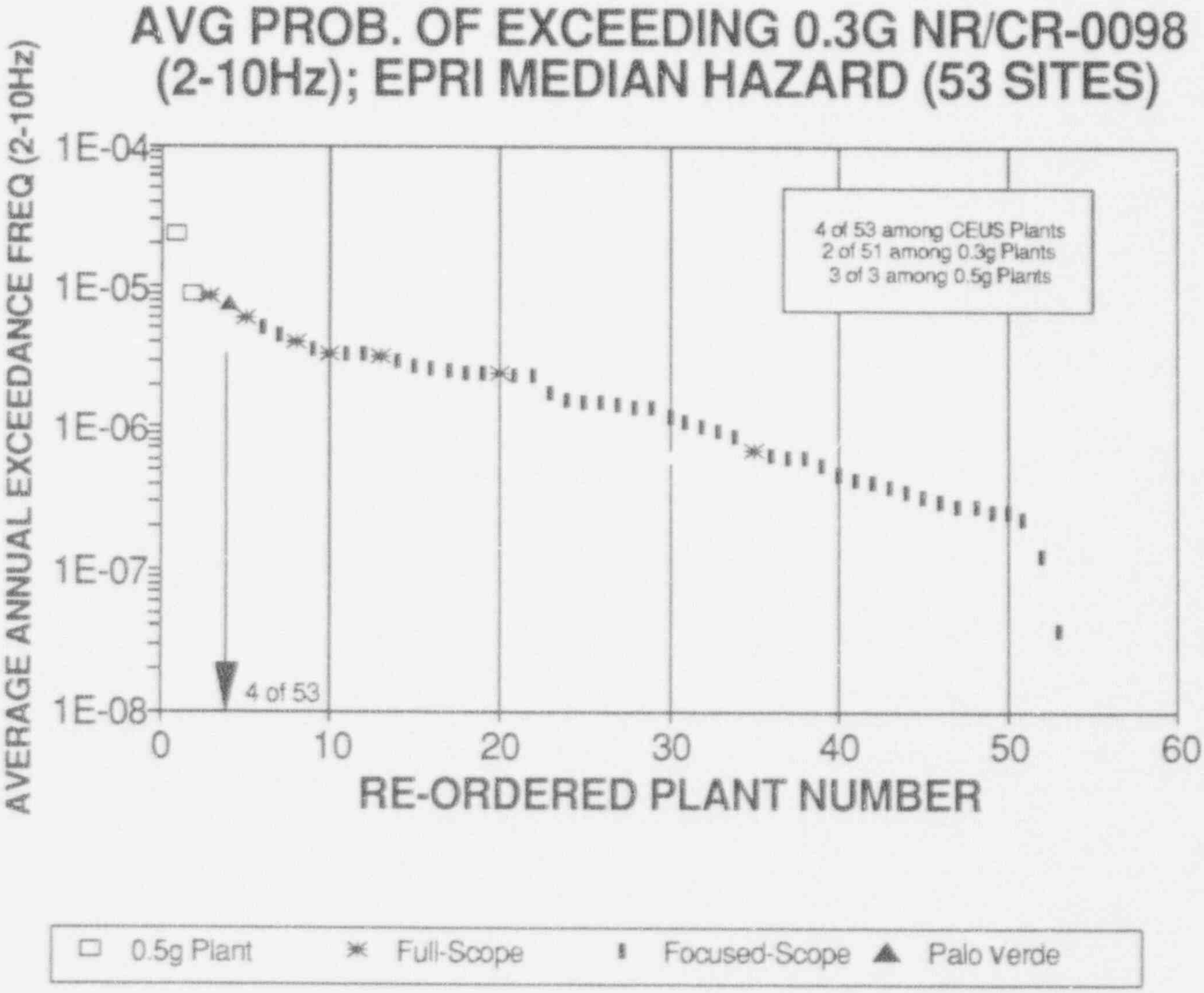


Figure D-11. Comparison of the average (over the frequency range of 2 to 10 Hz) median probability of exceeding the NUREG/CR-0098 median, 5%-damped spectrum anchored to 0.3g: comparison of results for the the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g CEUS plants and two 0.5g CEUS plants.

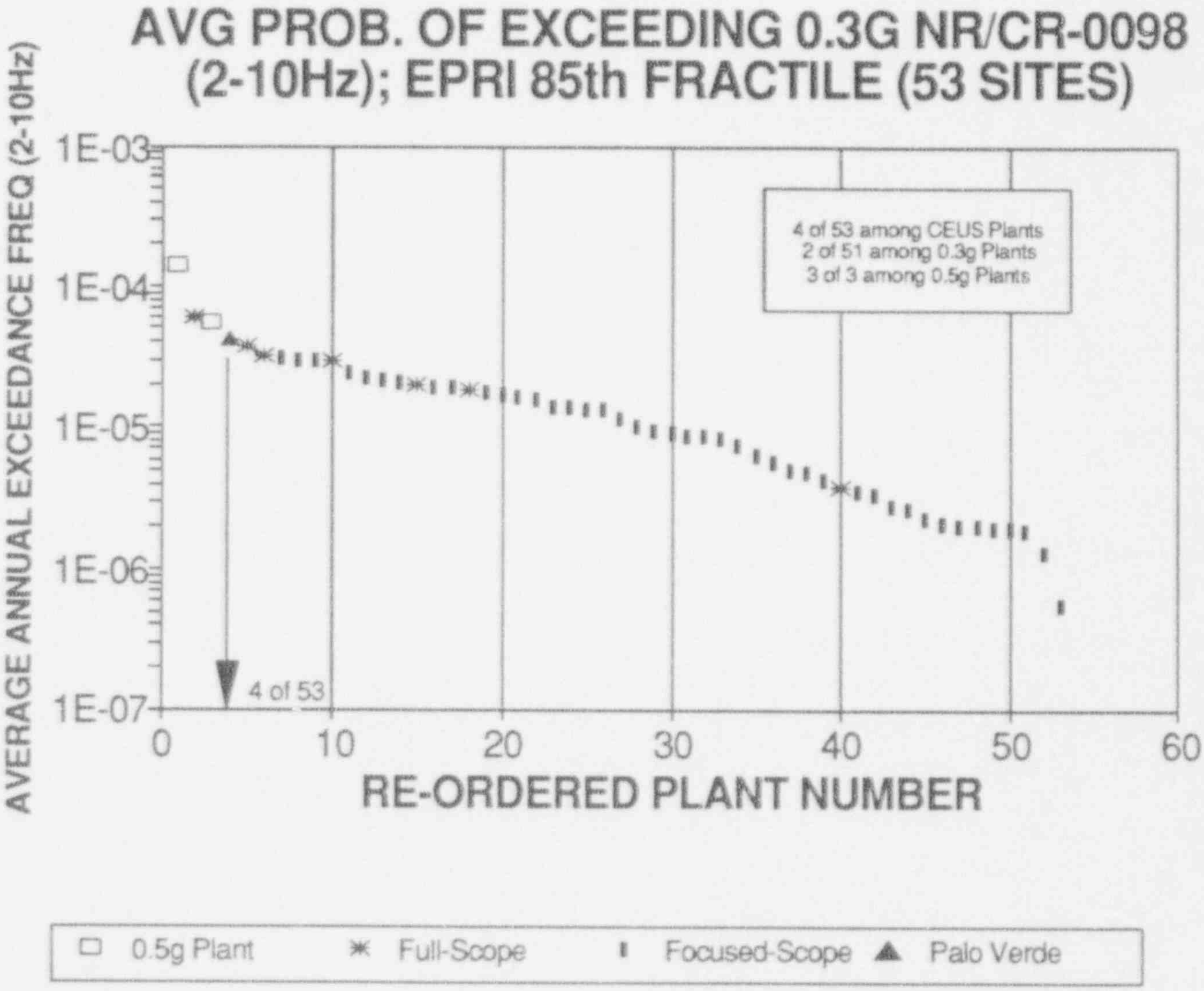


Figure D-12. Comparison of the average (over the frequency range of 2 to 10 Hz) 85th-fractile probability of exceeding the NUREG/CR-0098 median, 5%-damped spectrum anchored to 0.3g: comparison of results for the the Palo Verde site with similar results for 50 full-scope and focused-scope 0.3g CEUS plants and two 0.5g CEUS plants.